

DOT/FAA/ND-98/2

Office of Communication,
Navigation, and Surveillance
Washington, DC 20591

Heliport Lighting – Configuration Research

Scott A. Fontaine
Adina C. Cherry
Edwin D. McConkey

Science Applications International Corporation
Air Transportation Systems Operation
Arlington, Virginia 22202

19990202 052

November 1998
Final Report

This document is available to the public
Through the National Technical Information
Service, Springfield, Virginia 22161.



U.S. Department of Transportation

Federal Aviation Administration

DTIC QUALITY INSPECTED 2

This document is disseminated under the sponsorship of the United States
Department of Transportation in the interest of information exchange.
The United States Government assumes no liability for the contents or use thereof.

The United States Government does not endorse products of manufacturers.
Trade or manufacturer's names appear in this document solely because
they are considered essential to the object of this report.



U.S. Department
of Transportation
**Federal Aviation
Administration**

800 Independence Ave., S.W.
Washington, D.C. 20591

NOV 20 1998

Dear Colleague:

This report is one of several documenting FAA/Industry research and development efforts on heliport lighting. Reports of interest include the following:

FAA/ND-98-1, Heliport Lighting - Technology Research

FAA/ND-98-2, Heliport Lighting - Configuration Research

FAA/ND-98-4, Heliport Lighting - U.S. Park Police Demonstration

FAA/ND-97/20, Evaluation of a Heliport Lighting Design During Operation
Heli-STAR

These reports document the initial phase of an FAA/Industry effort to develop a cost-effective heliport lighting system for Global Positioning System (GPS) helicopter approaches. They speak of new technologies that could be of use as part of a heliport lighting system as well as military lighting systems that could be useful if optimized for civil heliport applications. The reports also document previous research that has attempted to determine what helicopter pilots need in the way of visual cues for heliport approaches at night or in poor weather.

While these reports address a wide range of heliport lighting issues, they raise more questions than they answer. The possibilities of dealing with these issues are exciting but the range of potential solutions is very broad. We do not yet have answers to all the questions of interest to those who wish to implement improved heliport lighting systems. Additional work is needed. In particular, candidate lighting systems need to be developed, installed, and tested in a variety of operational scenarios in different environments throughout the country. If we were to do all that seems appropriate, the cost would far exceed the available funding. Thus, we are looking for ways to achieve the maximum near term benefits within the limits of available funding. With this in mind, we look to Industry for their recommendations.

The FAA is looking for ways to accomplish more with smaller budgets. By working in Government/Industry partnerships, we have seen that it is possible to do more with less. After

reviewing the reports listed above, we request that you write us with your advice on what future heliport lighting research efforts would be most likely to meet your operational requirements. Please send your comments to:

Federal Aviation Administration
General Aviation and Vertical Flight Program Office, AND-710
Attn: Robert D. Smith
800 Independence Ave. SW
Washington DC 20591

By soliciting Industry's advice, we hope that your ideas will better enable us to choose those heliport lighting research projects that will meet your needs. Your advice would be most effective if we could receive it by January 15, 1999. We appreciate your assistance and we look forward to continued FAA/Industry cooperation on matters such as this.

A handwritten signature in black ink that reads "Steve Fisher". The signature is written in a cursive, flowing style with a long horizontal stroke at the end.

Steve Fisher
Acting Manager, General Aviation
and Vertical Flight Program Office

Technical Report Documentation Page

1. Report No. DOT/FAA/ND-98/2		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle Heliport Lighting – Configuration Research				5. Report Date November 1998	
				6. Performing Organization No.	
7. Author (s) Principal Author: Scott Fontaine Contributing Authors: Adina Cherry, Edwin McConkey				8. Performing Organization Report No.	
9. Performing Organization Name and Address Science Applications International Corporation (SAIC) 1213 Jefferson Davis Highway, Suite 1500 Arlington, VA 22202				10. Work Unit No. (TRAIS)	
				11. Contract or Grant No. DTFA01-93-C-00030, Task Order C4	
12. Sponsoring Agency Name and Address Federal Aviation Administration General Aviation and Vertical Flight Program Office, AND-710 800 Independence Avenue, S. W. Washington, D. C. 20591				13. Type Report and Period Covered Final Report	
				14. Sponsoring Agency Code AND-710	
15. Supplementary Notes AND-710 General Aviation and Vertical Flight Program Office					
16. Abstract This report develops a methodology for researching and designing heliport lighting systems with particular emphasis on lighting system configurations. The report also catalogs lighting system components, subsystems, and systems identified to date. The main objective of this effort is to develop a basis from which to form a more efficient lighting system for instrument approaches to heliports using the Global Positioning System (GPS). With the development of instrument approach procedures to heliports, the Federal Aviation Administration (FAA) is investigating the lighting requirements necessary to support these procedures. This report describes the initial efforts of this research and development activity.					
17. Key Words Helicopter Lighting Approach Heliport Rotorcraft Landing Visual Landing Aids Powered-Lift Vehicles Layouts				18. Distribution Statement This document is available to the public through the National Technical Information Service, 5258 Port Royal Road, Springfield, Virginia 22161.	
19. Security Classif. (of this report) Unclassified		20. Security Classif. (of this page) Unclassified		21. No. of Pages 68	
				22. Price	

TABLE OF CONTENTS

1.0	INTRODUCTION	1
2.0	BACKGROUND	3
3.0	METHOD	5
4.0	HELIPORT GROUPS	7
4.1	Rooftop Heliports	7
4.2	Ground-level/off-airport Heliports	7
4.3	Ground-level/on-airport Heliports	7
5.0	REQUIRED LIGHTING CUES	9
5.1	FAA Requirements	10
5.2	Conventional Lighting	13
5.3	A Methodology for Evaluating Required Lighting Cues	13
6.0	LIGHTING TECHNOLOGIES	17
6.1	Point Source Lighting	17
6.1.1	Light Emitting Diodes	17
6.1.2	Lasers	18
6.2	Diffused Lighting Technologies	18
6.2.1	Light Pipes	18
6.2.2	Cold Cathode Lights	18
6.2.3	Electroluminescent Lights	19
6.2.4	Fiber Optics	19
6.3	Retroreflective Markers	20
7.0	LIGHTING CONFIGURATIONS	21
7.1	Acquisition	21
7.1.1	Acquisition Cues	21
7.1.2	Acquisition Design Considerations	22
7.2	Line-up	23
7.2.1	Line-Up Cues	23
7.2.2	Line-Up Design Considerations	28
7.3	Glideslope	29
7.3.1	Glideslope Cues	29
7.3.2	Glideslope Design Considerations	32
7.4	Horizon	33
7.4.1	Horizon Cues	33
7.4.2	Horizon Design Considerations	35

TABLE OF CONTENTS (CONTINUED)

7.5 Closure Rate.....	35
7.5.1 Optical Expansion Rate	36
7.5.2 Optical Flow Rate	37
7.5.3 Optical Edge Rate	38
7.5.4 Use of a Glideslope Indicator to Interpret Closure Rate Cues.....	38
7.5.5 Alternative Closure Rate Cues	39
7.5.6 Closure Rate Design Considerations.....	39
7.6 Touchdown	40
7.6.1 Touchdown Cues	40
7.6.2 Touchdown Design Considerations	43
8.0 HELIPORT LIGHTING SYSTEMS	45
8.1 HILS and HALS	45
8.2 Operation Heli-STAR.....	47
8.3 A Design Case Study.....	49
9.0 CONCLUSIONS AND RECOMMENDATIONS	51
REFERENCES	55
APPENDIX A ACRONYMS	59

LIST OF FIGURES

Figure 1	Heliport Instrument Lighting System (HILS)	11
Figure 2	Heliport Approach Lighting System (HALS)	12
Figure 3	Tactical or "Field Expeditionary Lighting"	24
Figure 4	Vertical Light Pipe and Line-Up Cue	24
Figure 5	Rooftop Heliport with Vertical Drop Line of Lights	25
Figure 6	Runway, Rollway or Pad Centerline Lighting	26
Figure 7	U.S. Navy Laser, Extended-Range Line-up System	27
Figure 8	Helicopter Approach Path Indicator (HAPI)	31
Figure 9	U.S. Navy Fresnel Lens Optical Landing System (FLOLS)	32
Figure 10	Three-Color Glideslope Indicator	33
Figure 11	Lower-Cost "Alignment of Elements" Glideslope Indicator	34
Figure 12	Optical Expansion Rate	36
Figure 13	Heliport Surface Lighting	37
Figure 14	Heliport Perimeter Surface Lighting	40
Figure 15	Tactical Lighting System	42
Figure 16	Floodlights	43
Figure 17	HILS and HALS with Perimeter Light Enhancement and Optional Centerline Lights	46
Figure 18	Prototype Lighting System Installed at NationsBank Southside Heliport in Atlanta	48
Figure 19	Prototype Heliport Lighting Design Using the Study Methodology	50

LIST OF TABLES

Table 1	Pilot Cues Provided by Various Lighting Elements	14
Table 2	A Partial List of Various Glideslope Indicators	31

1.0 INTRODUCTION

This report documents an evaluation of heliport lighting requirements for instrument approaches sponsored by the Federal Aviation Administration (FAA). Although preliminary, this research is presented to assist any concurrent or future efforts to investigate lighting requirements for instrument approaches to heliports using the Global Positioning System (GPS).

This report is one of several recent FAA-sponsored reports on heliport lighting. Other reports addressing this topic include:

DOT/FAA/ND-97/20, Evaluation of Heliport Lighting Design During Operation Heli-STAR

DOT/FAA/ND-98/1, Heliport Lighting – Technology Research

DOT/FAA/ND-98/4, Heliport Lighting – United States Park Police Demonstration

2.0 BACKGROUND

Until now, civil helicopter operators have been conducting most Instrument Flight Rules (IFR) operations to and from an airport environment. Approaches have generally been initiated at speeds above 90 knots and deceleration, hover, and air taxi have been conducted in the standardized runway and taxiway lighting environments. With very few non-precision instrument approaches and no precision approaches commissioned at heliports, there has been little emphasis on IFR heliport lighting system development. Current heliport lighting systems were designed for Visual Flight Rules (VFR) operations. Initial developments of heliport lighting systems for IFR operations were modeled on fixed-wing requirements and operating environments and use 1,000 feet of approach and pad lighting, which is longer than most heliport Final Approach and Takeoff Areas (FATO).

This report describes ongoing research on heliport lighting. It identifies catalogs, summarizes, and analyzes the results of research, development, test, and evaluation efforts pertaining to heliport/vertiport lighting requirements for instrument approaches. This report develops a methodology for researching and designing heliport lighting systems with particular emphasis on lighting configurations. It also catalogs lighting system components, subsystems, and systems identified to date. The main objective of this effort is to form a basis from which to develop safe and effective lighting systems for instrument approaches to heliports.

3.0 METHOD

The development of lighting systems to support instrument approaches to heliports starts with a review of existing heliport layouts. By looking at just a few of the thousands of registered heliports in the United States (U.S.), it is obvious that a "one size fits all" approach to heliport lighting system design has decided limitations. Due to the wide variety of heliport layouts and operational environments, engineers and architects have not identified one system that meets all needs in all situations. Consequently, there is a need to develop guidelines that will address the operational and safety requirements for IFR approaches to heliports for a variety of operational scenarios.

Two simplifications are proposed to clarify a future heliport designer's task. First, the heliports have been grouped into three broad siting categories: rooftop, ground-level/off-airport, and ground-level/on-airport. Second, the cues required to fly an approach to a heliport have been grouped into six categories: acquisition, line-up, glideslope, horizon, closure rate, and touchdown. The combination of these two groupings is intended to allow the designer to mix and match lighting system components to develop a complete system providing the necessary cues for a safe approach to the heliport in question. Testing at a variety of heliports in a variety of environments will be necessary to determine if this approach is safe and effective in all cases.

Since some of the lighting configurations discussed are dependent on a specific lighting characteristic, lighting technologies are briefly listed and described. The list is not comprehensive and not all of the lighting technologies listed have been evaluated. Listed here are many technologies known to have been used in heliport lighting systems or considered to have potential for future use.

The heliport lighting system components and systems laid out in this report have not been thoroughly evaluated in the IFR environment. Most are in the preliminary design phase and are put forth for consideration in future evaluations. Each component or subsystem is first grouped by the approach cues that the lights can provide. Most of the components provide multiple cues. For example, a vertically-mounted light pipe provides an acquisition cue by virtue of its unique characteristics, a line-up cue (when used in conjunction with ground lights), horizon (derived from a fixed vertical line) and touchdown cues (when placed in front of the landing pad). The configurations included in this report are annotated with brief comments related to the definition of the cues provided, along with a preliminary evaluation of the cues.

The components and subsystems are then grouped into possible complete heliport lighting systems configured for one or more of the three groups of heliports: rooftop, ground-level/off-airport and ground-level/on-airport. Thorough evaluation of these configurations is recommended before the FAA could recommend them for operational use.

4.0 HELIPORT GROUPS

Heliports, of many different designs, are found in a large variety of environments and simplification is difficult. The groupings offered here allow variation within each group. For instance, a rooftop heliport can include heliports on the highest roof of a building, the highest roof of a building with a higher roof on the building next door, the roof of a parking garage with a hangar immediately in front, etc. The heliport groups were picked to allow designers to work with generic heliports while designing subsystems that could be placed in such a way that uses the environment to maximize the cues provided to the pilot. For instance, a ground level/on-airport heliport implies a pad that is located on a runway, taxiway or ramp and the designer may not be able to use vertical light arrays. In fact, the location may allow only flush-mounted lights. The rooftop category implies, however, that a structure may be in close proximity and might be used to support a vertical array of lights.

The environment can have a significant effect on the relative importance of each lighting cue. Under clear daylight conditions, all the required visual cues are generally available. Under reduced visibility conditions, including darkness, the availability of the required cues varies with the environment. In the absence of a natural horizon, often encountered in approaches to very dark areas, the horizon cue may be the most critical for the designer to supplement. In an urban environment, the large number of lights provides a relatively high ambient light level and a strong natural horizon. In urban environments, obstacles may mean that the glideslope cue is the critical lighting cue.

4.1 ROOFTOP

Rooftop heliports are often characterized by limited space, close proximity to the vertical surfaces of buildings or structures (such as parking garages), and a relatively high surrounding ambient light level. The pad itself may be dark in contrast to the surrounding city lights. These heliports are normally located in the midst of large numbers of point-source lights on city streets, buildings, and signs.

4.2 GROUND-LEVEL/OFF-AIRPORT

The largest grouping, ground level/off-airport heliports, includes the many possible variations of ground-level heliports. This group is difficult to generalize. It can include a city-center heliport surrounded by tall, brightly illuminated buildings and a rural medical clinic's heliport surrounded by unlit or poorly lit streets and utility poles. A heliport in this group may have plenty of land available for the installation of lighting systems or it may be located immediately adjacent to a hangar, hospital, or passenger facility. A few ground-level heliports are located on piers or barges tied to piers and may be similar to a rooftop heliport.

4.3 GROUND-LEVEL/ON-AIRPORT

This grouping differentiates a unique category of heliports with evolving requirements. Most on-airport heliports are currently not much more than a landing spot at an airport. Approaching

helicopters are typically merged with fixed-wing traffic and make the initial approach to the active runways. On final approach, the helicopter is redirected to complete the approach to the taxiway or may be directed to a helipad on the ramp. In these cases, the airport approach and runway lighting systems provide the required lighting cues. Lights, usually flush mounted, that define the perimeter of the landing pad are typically the only lights uniquely associated with the heliport. At some larger airports, non-conflicting helicopter traffic patterns have been developed that allow helicopters to approach, land, and depart the airport traffic area without using the fixed-wing traffic pattern during VFR operations. During IFR operations, however, all helicopter traffic is merged with fixed-wing traffic for instrument approaches to the active runways. The merging helicopter traffic, typically approaching from shorter distances and lower altitudes than the fixed-wing traffic, often incur delays that make a schedule difficult to maintain. This group is differentiated in order to provide for future growth and anticipated changes in the management of helicopter traffic in and around airports. It is anticipated that there will be a requirement for an on-airport heliport to include a dedicated lighting system supporting a helicopter-only instrument approach to the heliport.

The ground level/on-airport heliport currently requires minimal lighting that supports air taxi, touchdown, and take-off operations. Future ground level/on-airport heliports are anticipated to require a complete, dedicated lighting system that supports a helicopter-only instrument approach to, and departure from, the heliport. If designed to allow helicopter operations without interfering with fixed-wing operations, such helicopter procedures could increase airport capacity and provide schedule efficiency benefits to both airplane and vertical flight operations.

5.0 REQUIRED LIGHTING CUES

The required lighting cues identified below are appropriate for IFR and VFR approaches. The visual segment of an instrument approach starts at the Decision Waypoint (DWP) or Missed Approach Waypoint (MAWP) of an instrument approach when the pilot changes from an instrument scan to a visual scan. A visual approach can be initiated from a wide range of directions at some heliports. However, heliport approaches are often restricted by local traffic patterns and/or obstacles to one or more specific approach courses. These approach courses are most often defined by heliport operators and are disseminated to the pilots flying to the heliport via training, familiarization flights, and locally produced diagrams. A better means needs to be found to standardize the presentation and distribution of information that pilots need for safe approaches to, and departures from, heliports.

During any approach to a heliport, the pilot will have to acquire the landing environment visually, transition to a visual scan (if transitioning from an instrument approach), maneuver to a specific approach course (if performing a visual approach), descend on a glideslope between 3 and 9 degrees¹, and proceed to a safe hover and landing. The necessity to revert to an instrument scan in order to gain information not available from the landing environment adds to workload during the approach. Therefore, an optimal lighting system will provide all the information, in the form of visual cues, that the pilot requires to land the helicopter with an acceptable workload. These required external visual cues are:

- Visual acquisition of the landing environment to include:
 - ◆ Identification as a heliport
 - ◆ Early acquisition in conditions of reduced visibility
- Lineup
- Closure rate
- Horizontal reference (horizon)
- Glideslope, that provides:
 - ◆ Relative altitude
 - ◆ Obstacle clearance
- Touchdown, which includes:
 - ◆ Transition to hover and hover position cues
 - ◆ Hover altitude and hover altitude rate cues

These cues are consistent with the required information identified by Navy studies (reference 1) and with the FAA's National Airspace System (NAS) requirements (reference 2). The information not included in the above listed cues can be obtained by other means, (e.g., radio communications and publications).

Not only are these cues required when approaches are going well (that is, when the pilot is on glideslope and on course with a constant rate of descent (stabilized) at the DWP), but these cues

¹Shallower or steeper glideslope angles are possible, but unlikely. Shallower angles are unnecessarily noisy and steeper angles are performance limited in many helicopters.

must also assist the pilot who is off course and/or glideslope to complete corrective action. For an approach to a confined area such as a city center, visual guidance may be required to inform or warn the pilot when the aircraft is too far off course, off glideslope, or too fast to effect a safe landing.

5.1 FAA REQUIREMENTS

The FAA's Heliport Design Advisory Circular (AC) (reference 3) recommends that a Heliport Instrument Lighting System (HILS) with an enhanced perimeter lighting system be installed to support non-precision instrument approaches. The guide also states that Heliport Approach Lighting System (HALS), the enhanced perimeter lighting system, and HILS are "... necessary for a helicopter precision instrument approach procedure with the lowest minimums." The AC notes that, "The FAA is continuing its study of configurations for precision instrument approach lighting systems."

NAS-SR-1000 (reference 2) requires a HALS to provide the pilot with "... visual information on horizontal path alignment, roll guidance, deceleration or rate-of-closure determination, and height perception for precision approaches." These requirements are similar to the requirements for airport approach lighting systems with the addition of a requirement for closure rate information. NAS SR-1000 also states that the desired performance for a HALS is an effective visual range during clear weather of at least 3 statute miles (mi) during the day and 20 mi at night.

FAA Order 8260.37, Heliport Civil Utilization of Collocated Microwave Landing Systems (MLS) (reference 4) requires that "An operational HILS shall be mandatory for all MLS approaches to heliports. Visibility values at heliports with no HALS shall be increased by ½ mi. The cumulative total visibility for an inoperative HALS, or no HALS, need not exceed 1.5 mi. Therefore, to ensure necessary deceleration cueing with NO HALS, ADD ½ mi to the visibility value..." The HILS is 210 feet by 420 feet and is depicted in figure 1. The HALS is a 900-foot long system depicted in figure 2.

FAA Order 8260.42A, Helicopter Non-precision Approach Criteria Utilizing the Global Positioning System (reference 5), grants a credit for HALS: "Where a HALS (or equivalent) is installed, the visibility may be reduced by ¼ mi." The order also recommends the use of HILS. "A HILS is recommended for all helicopter GPS approach operations. Approved runway lighting is adequate for approaches to runways. When a HILS is installed, the system shall be in alignment with the course from the MAWP to the helipoint."

The GPS non-precision approach order (8260.42A) recognizes the possibility of a HALS equivalent and authorizes a ¼ mi credit for its use. A credit would be based on two factors, the extension of the landing environment closer to the MAWP (HALS and HILS extend the landing environment more than ¼ mi toward the MAWP) and the necessary deceleration cueing. The growing numbers of GPS non-precision approaches will likely create a demand for a HALS equivalent. A possible HALS equivalent might use some form of "lead-in" lights that are visible to a pilot at the MAWP or DWP.

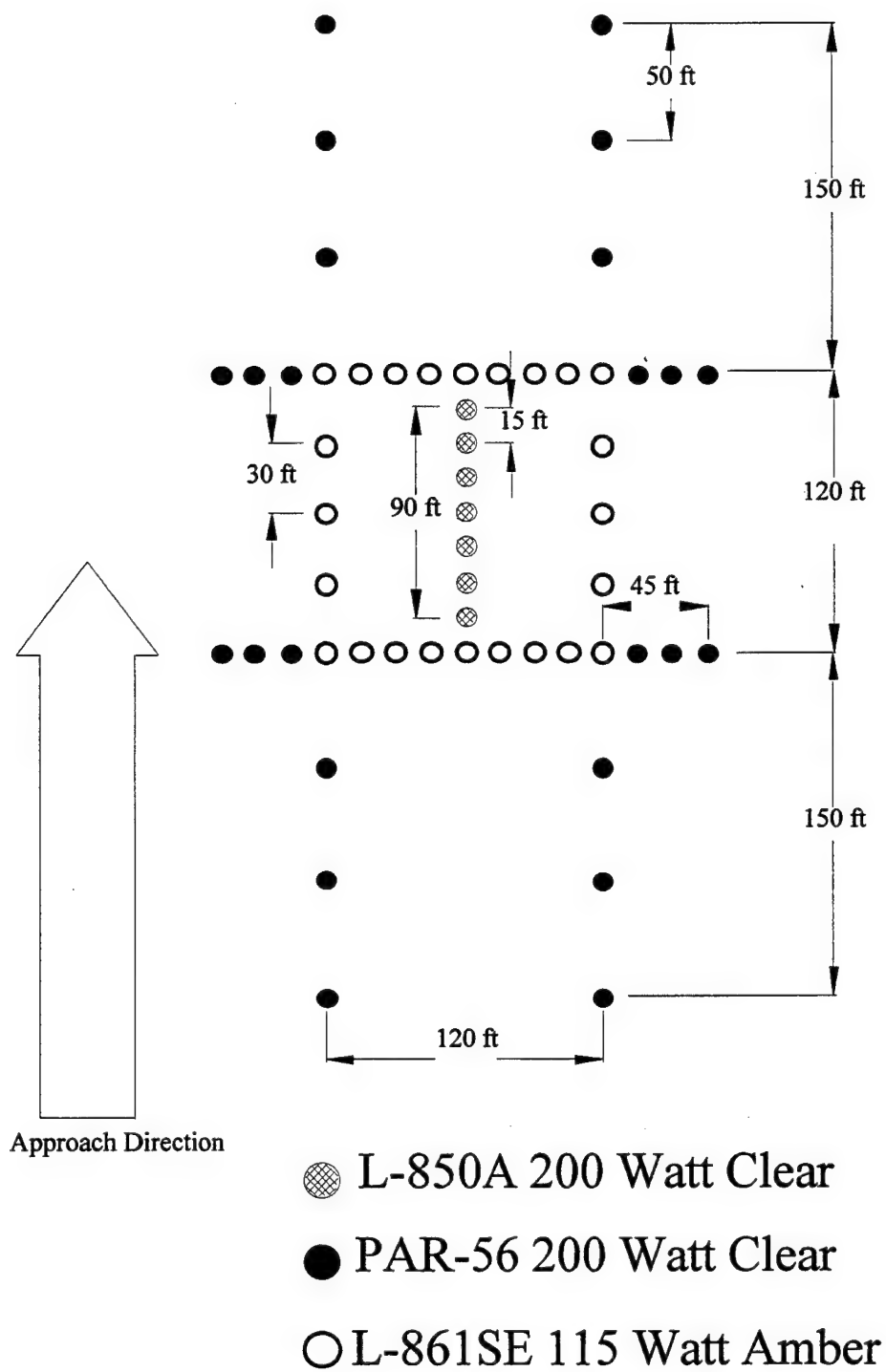


Figure 1 The Heliport Instrument Lighting System (HILS)

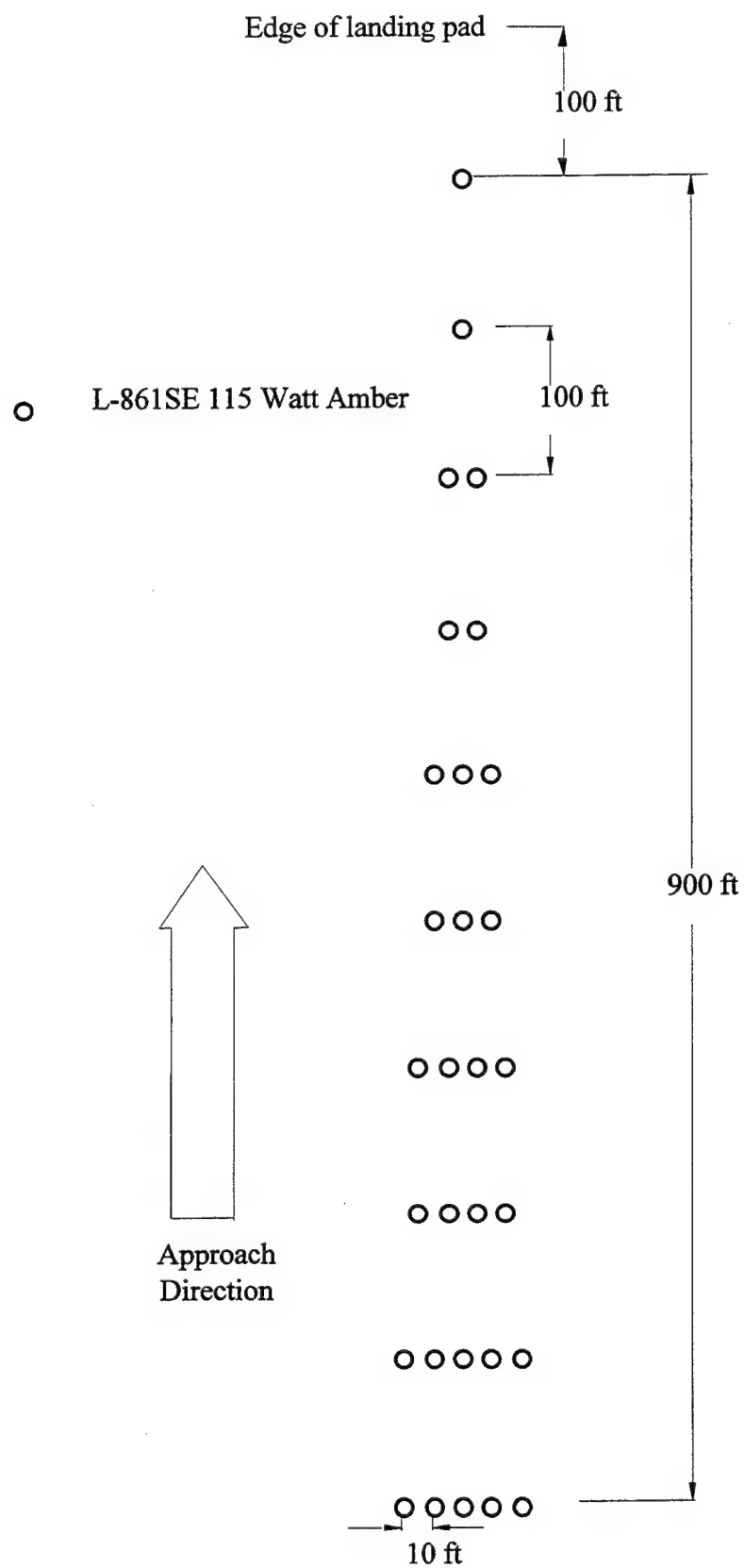


Figure 2 The Heliport Approach Lighting System (HALS)

Finally, two aspects of FAA lighting certification and documentation should be discussed. The FAA publishes a list of approved lighting that can be purchased with Federal support, such as Airport Improvement Program (AIP) funds. In some cases, insurance companies and local and state officials have limited a heliport lighting designer's choices to this list of FAA-approved lighting. It is in the best interest of the industry to expand the FAA list of approved lighting in order to remove any barriers, however artificial and unintentional, to the introduction of new lighting technologies that may improve VFR and IFR heliport operations.

As the FAA develops and refines the requirements for heliport instrument lighting, care must be taken to develop all resulting specifications as functional performance specifications that detail the required characteristics of the light output and not merely the characteristics of a light source. As lighting technology has advanced, there are often several ways to produce a light output. Some of the current airport approach lighting specifications characterize the lamp that is required to match up with a particular filter that will be used in the lighting system. It is possible that a colored light source could be substituted for the lamp and filter combination, but the colored lamp would not meet the specification requirements. The heliport approach lighting development described here will help to avoid this trap by defining the required cues that must be provided to the pilot. This should ease the introduction of new lighting technologies.

5.2 CONVENTIONAL LIGHTING

Visual cues can be provided by a variety of methods. Some conventional examples are listed in table 1. Lighting systems often provide multiple cues. Some of these cues are weak and may not be sufficient to fully satisfy a specific requirement. Also, some of these lighting systems may have undesirable attributes, such as poor maintainability, high life-cycle costs, a requirement for excessive real estate, interference with other lighting systems, interference with pilots' night vision, a tendency to cause pilot disorientation, or they may introduce a potential obstruction hazard.

5.3 A METHODOLOGY FOR EVALUATING LIGHTING CUES

Under a related task order, Science Applications International Corporation (SAIC) performed a search of both civilian and military literature regarding heliport lighting systems. This revealed extensive work done by the United States Navy. During their program entitled Navy Vertical Takeoff And Landing Capability Development (NAVTOLAND) (reference 1), the Navy performed a comprehensive analysis of information required by a pilot during approaches to ships. This analysis was much more specific than the FAA's requirements stated in NAS-SR-1000 (reference 2). One NAVTOLAND program report identifies 25 types of information required by a pilot on approach to a ship underway. The approach is divided into six terminal flight phase segments: homing, orientation, initial approach, final approach, hover, and vertical landing. The homing segment is unique to the ship environment, since it deals with ship course and speed and the relative motion problem of an approaching helicopter. The other segments apply to a civil heliport approach and were used in developing the required lighting cues. The information required is identified by the phases of flight and by the type of information required. This includes whether the magnitude and rate of error are required in addition to the direction of

Table 1 Pilot Cues Provided by Various Lighting Elements

Conventional Lighting Subsystems	CUES (s = strong m = medium w = weak)					
	Acquisition	Lineup	Closure Rate	Horizon	Touch-down	Glideslope
Beacon	w to m					
Approach	w to s	s	m ¹	m ²		w to m
Perimeter	w	w	w	w ³	w	
Glideslope Indicators	w	w	m ⁴			s
Perimeter Light Extensions (longitudinal + lateral)	m	m	m	m	m	
Approach Strobes (rabbit)	s	s				
Centerline Lights	m	m	w ⁵			
Surface Flood Lights	w		w		m	
Hangar Face Light ⁶	w		w	w	w	
Flood Lights	w		w		m	
Touchdown	w	w				

Notes:

- 1) If the lighting system is sufficiently long
- 2) If the approach lights contain rows of lights (of sufficient width) perpendicular to the approach course
- 3) If the perimeter is rectangular
- 4) Glideslope indicators allow the pilot to compute range from altitude and manage speed accordingly
- 5) Centerline lights on a long runway or rollway provide closure rate information as the helicopter passes over them
- 6) For landing pads immediately in front of a hangar or structure

error. The report also details operational situations where a warning is required. For example, a flashing red signal from a glideslope indicator can be used to warn the pilot that the aircraft is dangerously low on the approach.

After determining the information required by the pilot to fly each segment of the approach, the NAVTOLAND report details a methodology for evaluating the suitability of the candidate lighting system or subsystem that is designed to provide that information. The evaluation should address both quantitative and qualitative characteristics of the lighting display.

Quantitative characteristics include:

- Accuracy
- Azimuth coverage
- Elevation coverage
- Resolution: the smallest change that can be displayed
- Sensitivity: the magnitude of display change per unit of true value change

Qualitative characteristics include:

- Discrimination: the range at which the display can be discriminated from other displays
- Intelligibility: can the display be understood?
- Interpretability:
 - ⇒ How difficult is the display to use?
 - ⇒ Does the pilot have to interpret the displayed information or is it intuitive?
- Responsiveness: is there time lag in the displayed information?
- Simplicity
- Visual compatibility:
 - ⇒ Is the display compatible with other aspects of the pilot's total visual task?
 - ⇒ Is it much brighter or dimmer than ambient lighting conditions?
 - ⇒ Is the display compatible with each segment of the approach?

Based on the results of research to date, workload is a qualitative characteristic that should be included in the evaluation of a lighting system or display. Workload is dependent on some of the quantitative measures, such as resolution and sensitivity, as well as some of the qualitative measures, such as interpretability and intelligibility. There are measures to quantify workload, but a typical pilot response to high workload is fixation on one display or task, or the dropping of one display or task from the pilot's scan. During this research, a pilot was observed while flying a glideslope indicator and visual line-up indicator. Due to some of the factors mentioned above, the workload was high enough that the pilot did not slow the aircraft sufficiently to complete a safe landing and was forced to fly a missed approach.

Although it was not possible to evaluate all the lighting components and subsystems identified in this report, the authors felt strongly that it was important to address the value of this methodology and the work accomplished in the NAVTOLAND study. It is a valuable reference and is consistent with the intent of this report, that is, to document findings to support future lighting efforts. An equivalent requirement analysis for the civil heliport is made more difficult, however, by the variety of operational environments encountered.

6.0 LIGHTING TECHNOLOGIES

Most lighting systems used to date have employed incandescent lights in one form or another. Two exceptions that come to mind are Xenon flash tubes and electroluminescent (EL) lighting, although there may be others. The lighting at aviation landing sites has been primarily incandescent. Recent research efforts have attempted to review alternative lighting technologies. Some have been around for years and have not previously been used in the aviation field, and some are relatively new technologies that have only recently become cost effective. A number of these alternative technologies show promise as potential components of heliport and vertiport lighting systems.

6.1 POINT SOURCE LIGHTS

Point source lights are characterized by a very bright point of light typically generated by a glowing filament or arc. These lights are most often shielded from direct view by a pilot because of the negative impact on night vision adaptation and because of the "after- image" effect. If a bright light is viewed directly, it often leaves an after-image on the retina that continues to be seen for several seconds or longer. If incandescent lights are not shielded, they are typically filtered with colored lenses, or directed away from the pilot. Exceptions to this are approach lighting systems where hundreds of 300-watt incandescent lights are aimed at the pilots of approaching aircraft.

Point source lights commonly used in aviation are the common tungsten filament and the high intensity halogen incandescent lights. Halogen is used to slow the vaporization of the tungsten filament and increase the life of the lamp. Point source lights new to the aviation field are light emitting diodes (LED) and lasers.

6.1.1 Light Emitting Diodes

An LED is a semiconductor diode that emits light. The beam is not as narrow or as powerful as that of a diode laser, however, it is safer. By forward biasing an LED, the charge carriers (electrons and holes) can move across the semiconductor junction and release photons. Lenses are often used to focus and collimate the light beam. Depending on the type of semiconductor material used, the wavelength (color) of light emitted can range from the visible to the far infrared spectrum. LED's can be manufactured to produce red, yellow, green, and most recently blue light. LED's have a typical output power of tens of microwatts and are grouped together to increase the total output.

An LED replacement traffic light is brighter than the original incandescent lamp and uses only one-tenth as much energy. The LED's are about six times as durable, and are guaranteed for six years. LED's can be clustered together to produce a form-fit replacement for incandescent lamps or can be strung together in series that produce lines of light.

6.1.2 Lasers

Gas lasers are typically expensive to acquire and expensive to operate, thus they are not practical for use in lighting systems. Recent advances in diode lasers, however, are promising. Diode lasers are still more expensive than most other light sources, but may have advantages worth the added expense. Diode lasers also have lower installation and operating costs than gas lasers.

A diode laser is an LED with two important differences:

- a. The operating current is much higher.
- b. Two of the ends of the laser diode are aligned parallel to each other. These ends act as aligned mirrors that reflect the light back and forth in order to get as much amplification as possible.

Diode lasers have been used to provide the light source for a military glideslope indicator and localizer (line-up) and are scheduled to be deployed on aircraft carriers to support fixed-wing operations.

6.2 DIFFUSED LIGHTING TECHNOLOGIES

6.2.1 Light Pipe

The light pipe is a hollow tube with a reflective semi-transparent coating on the inside. A light is mounted on one end, with a filter (if color is desired). The light is reflected along the length of the tube, emitting a uniform light along its length. The light pipe provides a unique line of light that is easily identified in a high light density urban environment. Furthermore, it uses only one light source. A mirrored film can be inserted to limit the portion of the circumference of the tube that emits light. This has the effect of both limiting the viewing angle of the light pipe and increasing the intensity of the emitted light (since the area of transmission is decreased). Light pipes are presently being used by the United States Coast Guard (USCG) to provide obstruction identification and channel line-up information to maritime pilots. In a heliport prototype lighting system (references 21 and 24), the light pipe was mounted vertically to provide acquisition, line-up, and hover cues.

6.2.2 Cold Cathode Lights

Cold cathode lights also provide a light that is very different from the incandescent "point source" lights found in urban environments and from those commonly used in aviation lighting. These lights use a gas filament that tends to disperse the light instead of a hot metal filament that burns an after-image onto the retina. Consequently, the lights leave very little, if any, after-image even after looking directly at the lights. The cold cathode lights are effectively monochromatic, and the lights tested in a prototype heliport lighting system had a greenish hue with a predominant wavelength of 512 nanometers. This wavelength (color) was selected to maximize the efficiency of the eyes' rods and cones at the low light levels encountered in nighttime

aviation (reference 6). Since these lights can be viewed directly without adverse effects on pilot vision, they were used to outline the perimeter of the landing pad and to provide illumination of the landing surface. The cold cathode lights had an added advantage in that they did not require dimming as the pilot got closer to touchdown. Thus, the same light intensity setting was used to provide long-range acquisition cues and touchdown cues.

The cold cathode lights have advantages in power consumption and reliability. The cold cathode lights convert 65 percent of their power to light while 35 percent is lost to heat. Incandescent lights convert only 5 percent of their energy to light and 95 percent is lost to heat. This is an efficiency factor increase of 13. The cold cathode lights also have a considerable maintenance advantage over conventional incandescent lights. The cold cathode lights have an approximate lifetime of 20,000 to 40,000 hours compared to a lifetime of about 2,000 hours for the incandescent lights.

6.2.3 Electroluminescent (EL) Lights

EL light panels were used in a prototype heliport lighting system (reference 21) to outline the perimeter of the landing pad. EL light panels also provide light without leaving an after-image on the retina. EL lighting uses phosphors to generate light by sandwiching a dielectric between two conducting surfaces. The result is a very thin, flat light panel that can be strengthened to allow it to be placed on landing and taxiway surfaces. Aircraft and ground vehicles can be taxied or driven over the panels. According to the manufacturer, the approximate life span is 28,000 to 45,000 hours. Intensity and the exact wavelength of the light are dependent on the frequency of the power source (reference 7). Preliminary testing at 60 Hertz (Hz), 120 Volts Alternating Current (VAC), has shown that the light output is not suited for the acquisition, line up, glideslope, and horizon cues. EL panels are considerably brighter if they are powered by a 400 Hz power source (using a 60Hz, 120 VAC and a frequency converter). A number of heliports throughout the U.S. are using such lighting. At both the high and low power settings, EL panels provide useful touchdown cues and the rugged, low profile installation makes EL panels very useful for illuminating heliport identification markings, taxiways, and parking areas.

6.2.4 Fiber Optics

Optical fibers are made from a clear material, such as glass or plastic. Two layers of material are used. Light travels through the core, which is surrounded by a cladding layer, keeping the light in the core. Because of differences in the refractive indexes of the layers, the cladding reflects light escaping from the core. This allows light to travel through the fiber for long distances, even if the fiber is bent. Recent advances in fiber optics manufacturing have produced fibers that are practical for aviation applications.

Two types of fiber optic lighting are available. End emitting fibers "pipe" light to a remote fixture, where a fitting on the end of the fiber can be used to replace a more traditional lamp. The advantage of "piping" light through optical fibers, is that the number of lights can be reduced and that the lamps can be located in a central, easy-to-access location, distant from the light output. This might be useful as a replacement for heliport lights that are difficult to replace (such as

lights at the edge of a safety net overhanging the perimeter of a tall building). The other type of fiber optic is a side-emitting fiber that has a translucent outer cladding that emits light along the length of the fiber. These fibers can be used to form a solid line of light similar in appearance to neon signs.

6.3 RETROREFLECTIVE MARKERS

Retroreflective surfaces reflect light back toward the light source. They have been used in highway signs and are now being used in aviation as a passive lighting system. Such systems may be suitable for use in remote areas without electrical power. Some retroreflective markers can be seen at night from over 3 nautical miles (nm) in clear weather and can be arranged in the same patterns as point source lights (reference 8). These markers are brightly colored to provide a daytime cue. The initial illumination of the pattern with the helicopter landing light provides a strong acquisition and identification cue similar to the initiation of a pilot-actuated lighting system. The unique character or appearance of the markers, when illuminated, is also an acquisition aid. The markers provide no surface illumination, however, since the majority of the light is reflected back toward the light source.

A quick-look evaluation of a retroreflective lighting system was promising. On short final approach, the intensity of the reflected light increased to a point that it started to become uncomfortable. By shifting the focal point of the spotlight so it was not pointed directly at the reflectors, the pilot could adequately control the intensity. The pilot could also increase the intensity of the retroreflective glideslope indicator (GSI) at the beginning of the approach by shining the light directly on the GSI. Even with the changes in pitch attitude required by the decelerating approach, it was not difficult to redirect the spotlight in order to maintain a comfortable intensity throughout the approach. A trainable spotlight, however, was necessary due to crosswind concerns and the need to control the intensity of the reflected light. In some scenarios, this is a significant human factors issue. With two people in the aircraft, the second person could handle the light at the pilot's direction, leaving the pilot free to fly the approach. This would be a manageable scenario. With a single pilot onboard, a high workload environment might keep the pilot so busy on approach that it would not be possible to manipulate the spotlight. This could be an unmanageable scenario.

7.0 LIGHTING CONFIGURATIONS

7.1 ACQUISITION

7.1.1 Acquisition Cues

The current Heliport Design Advisory Circular calls for an identification beacon flashing white-green-yellow pulses of light. Some work has been done with other beacons flashing the Morse code "H" (four quick flashes). The beacon must be placed so that it will not penetrate an approach, departure, or transitional surface or have the beam interfere with pilot or controller vision. Thus, the beacon may not be the primary visual acquisition cue for the rotorcraft pilot at the DWP of a precision approach. Other lighting components such as approach lights, perimeter lights, and GSIs may provide stronger acquisition cues to a pilot at the DWP. These cues may not be as strong, however, if the pilot is displaced laterally and/or vertically from the final approach course, or if the helicopter is crabbed away from the approach course. In such cases, and in visual approaches, the beacon may play a stronger role. As mentioned earlier, in order to qualify for a lighting credit, an approach lighting system must be visible to the pilot at the MAWP in conditions of reduced visibility.

A visual approach may actually be more demanding on the lighting system, in that the lighting system must provide acquisition cues that can be seen over a much broader area than required with the instrument approach. The required acquisition cues can be provided by one or more lighting components.

Acquisition cues include:

- Rotating beacons: white – green – yellow at 30 to 45 flashes per minute
- Strobe beacons: four short white flashes for Morse code "H" (It is possible to flash the heliport identifier in Morse code in order to provide a stronger identification cue.)
- Heliport identifier markings ("H") outlined with EL panel or floodlight
- Radio controlled lighting: a lighting system that is actuated at the pilot's command will provide an enhanced acquisition and identification cue when activated
- Retroreflective: similar to pilot controlled lighting, since retroreflective markers are only visible when lit by the approaching helicopter's landing light
- Unique color (might also be used to further increase the conspicuity of a beacon)
- Unique character: USCG studies (reference 9) have shown that lines of light have higher conspicuity (are more easily detected) than point light sources in a high ambient light background typical of cities. These studies have quantified this conspicuity advantage.
- Size: many helicopter pilots navigate around their respective metropolitan areas by means of landmarks in the form of large, uniquely lit buildings or signs (e.g., in Dallas, a building is outlined with green argon lights (similar to neon lights but using argon gas) and it provides a very visible landmark at a location close to the Dallas Vertiport).
- Configurations that use a combination of components may provide a unique system that stands out from the ambient lighting environment

- Extension of the landing environment toward the MAWP or DWP: currently HALS is the only certified heliport approach lighting system

More conventional acquisition lights such as beacons and strobes may not be suitable for all heliports. A rotating beacon at a Manhattan heliport was removed when it generated complaints from residents across the river. At this location, pilots indicated that the combination of high ambient lighting and surrounding landmarks provided adequate acquisition cues without the beacon. At many locations, this would not be an appropriate solution to community complaints. However, another potential solution would be the use of radio-activated acquisition lights.

An approach lighting system that provides an early acquisition in conditions of reduced visibility may qualify the heliport for a "lighting credit" and lower minimums that could improve the schedule reliability of operations at the heliport. Such an improvement may justify the installation of a HALS where there is sufficient real estate available. Lead-in lights, distinctive lights placed closer to the DWP or MAWP, have the potential to provide this early acquisition cue and may require less land than a HALS installation. It may be possible to place lead-in lights on top of buildings or above highways in such a way that dedicated land is not required.

Finally, acquisition also includes identification of the heliport as the intended point of landing. Identification has typically been provided by the combination of a geographical position and an acquisition cue at night or in low visibility. Position can be provided by electronic navigation aids or visual location of landmarks. Additional identification cues are the standard heliport markings, e.g., "H". This marking can be lit at night with floodlights, or much more effectively outlined with EL panels. A uniquely-lit building in close proximity can also be an identification cue.

7.1.2 Acquisition Design Considerations

Some design considerations are summarized below:

- Acquisition cues are site and operations dependent
- Acquisition cues can be provided by:
 - ⇒ Beacons (dedicated lighting)
 - ⇒ Navigation aids
 - ⇒ Unique environmental cues
 - ⇒ Lighting color
 - ⇒ Lighting characteristics (line of light, non-point source lights)
- Positive identification of the heliport can be provided by:
 - ⇒ Radio-controlled lighting
 - ⇒ Retroreflective markings
 - ⇒ Unique environmental cues
 - ⇒ Lighting color

It should be noted, however, that these cues have different levels of effectiveness.

7.2 LINE-UP

7.2.1 Line-Up Cues

A helicopter on approach to a hover does not require as precise a lineup as does a fixed-wing aircraft on approach to a landing. This does not obviate the requirement for line-up information but merely eases the resolution required for the line-up display.

Current airport and heliport lighting systems use long lines of approach lights to provide lineup guidance in support of instrument approaches. These vary from 2,400 feet at airports to 900 feet of lights in the HALS (figure 2). Testing of the HALS system (reference 10) revealed improved lateral tracking performance with HALS approach lights over approaches without HALS. Without HALS, pilots turning to intercept the final approach course typically never reached the approach centerline with just HILS and enhanced perimeter lighting (figure 1).

Military requirements have prompted the development of other systems to provide lineup cues. These lighting systems were designed to work in isolated areas, however, and not all have been evaluated in a well-lit city center. Special training, procedures, and proficiency requirements often overcome design limitations imposed on military systems by tactical considerations. These systems must be carefully evaluated and may require modification for civil use.

Tactical runway lighting systems (figure 3), constrained by complexity, weight, portability, and set-up time, use as few as two unidirectional lights placed 490 feet and 690 feet from the approach end of the runway. Some systems use additional lineup lights and sequential strobes (rabbit) to augment the line-up cue. These lights, when combined with runway edge lights, provide the necessary line-up information to the military pilot.

U.S. Army tactical lighting systems use four portable lights arranged in an inverted "Y" to provide line-up and touchdown cues with an absolute minimum number of lights. This illustrates a simple line of lights will not provide an adequate cue. The pilot requires additional lights arranged at right angles to properly orient the line-up line and resolve the visual picture with the actual attitude of the helicopter.

U.S. Navy ships with single helicopter landing spots use sequenced strobing centerline lights (rabbit) embedded in the landing surface. This line-up cue is augmented by "drop" lights extending the centerline at a vertical right angle below the flight deck and extended centerline lights on the hangar face, at a right angle above the flight deck. When an approaching helicopter is on centerline, the line-up lines appear as one continuous line. Pilots flying off centerline will see three line segments. (This effect is illustrated in figure 4, although only one vertical segment is illustrated, and in the civil heliport drawing of figure 5).

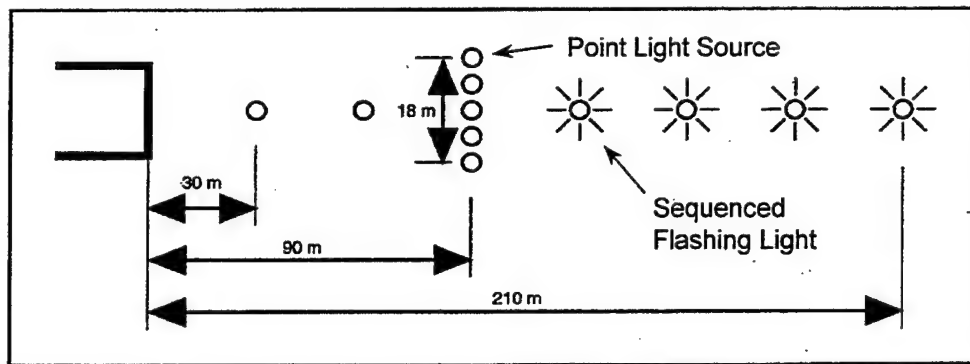


Figure 3 Tactical or "Field Expeditionary Lighting"

Note: This lighting system uses short lines of strobes or flashers set to flash sequentially to form a "rabbit" that provides a strong line-up cue.

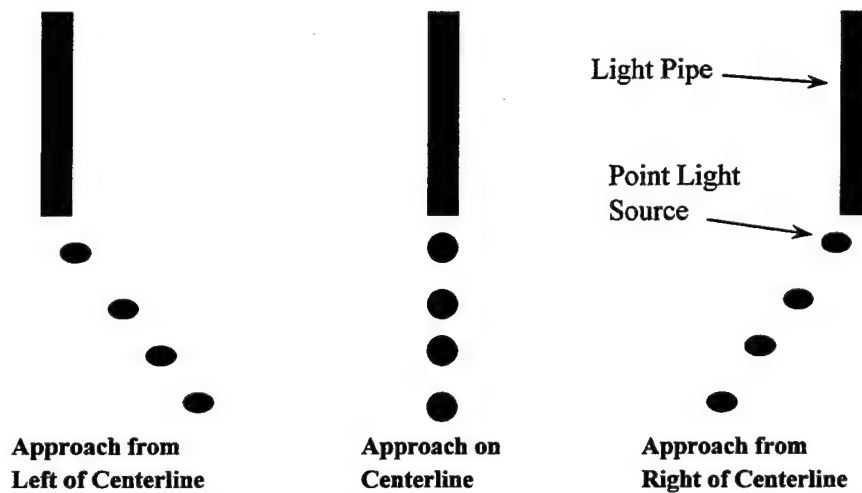


Figure 4 Vertical Light Pipe and Line-Up Cue

Note: when the approaching helicopter is off course, the vertical light pipe (or vertical line of lights) forms an angle with the extended line-up lights which provides an easily interpreted line-up cue.

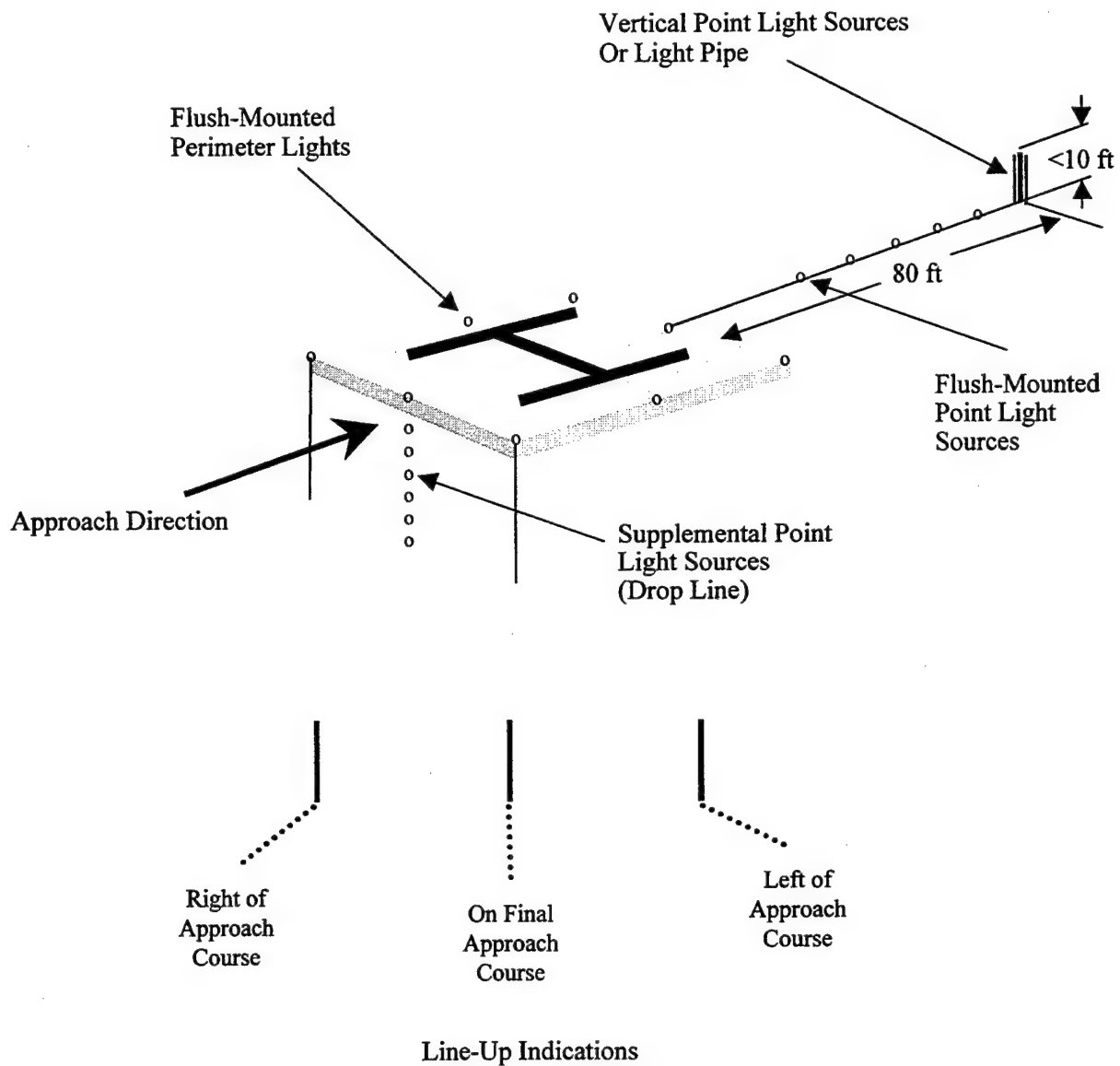


Figure 5 Rooftop Heliport with Vertical-Drop Line of Lights

Note: For rooftop heliports, a third line of lights extending vertically below the landing surface provides an even stronger, more easily interpreted line-up cue.

U.S. Navy Aircraft Carriers require precise line-up for safe landings. Some aircraft must land at 120 knots within 10 feet of centerline to avoid hitting parked aircraft. Carriers also use sequenced strobing centerline lights (rabbit) embedded in runway surfaces (figure 6) augmented by “drop” lights extending the centerline at a vertical right angle below the flight deck.

The U.S. Navy has also been evaluating a laser line-up device that, in early tests, has provided strong line-up cues out to 7 to 8 nm in clear weather (figure 7). The performance of this device has been evaluated at a ground-level/off-airport heliport in Washington, DC. Because local airspace restrictions allowed a maximum approach length of only 2 nm and because precise line-up was not required, this system was not well-suited (course width was too narrow) for the evaluation heliport (reference 24). The system uses corridors of colored steady and flashing lights to indicate direction and magnitude of deviation left and right of course. The small size (point source) of the display, low intensity (designed for the darker maritime environment), and narrow corridors forced the pilots to concentrate intensely on the display. The evaluation recommended a brighter display and wider corridors for use in heliport lighting systems. Wider corridors are required to reduce the workload required to stay on the desired course during the high workload final approach phase where the helicopter is simultaneously descending and decelerating. The level of precision should match the requirements of the operational environment.

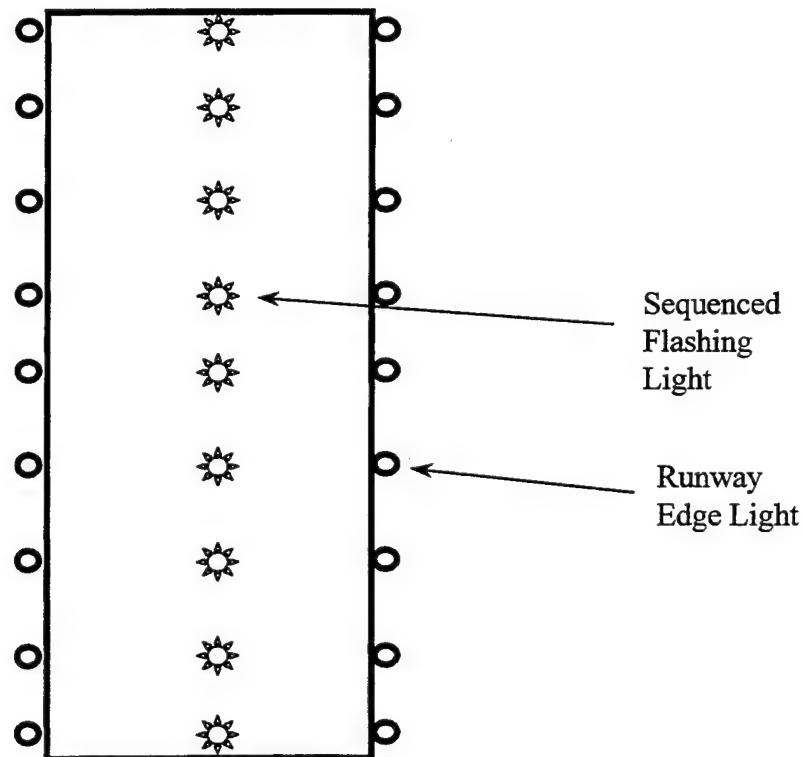


Figure 6 Runway, Rollway or Pad Centerline Lighting

Note: Centerline lighting can also be flashed in sequence to produce a “rabbit” effect.

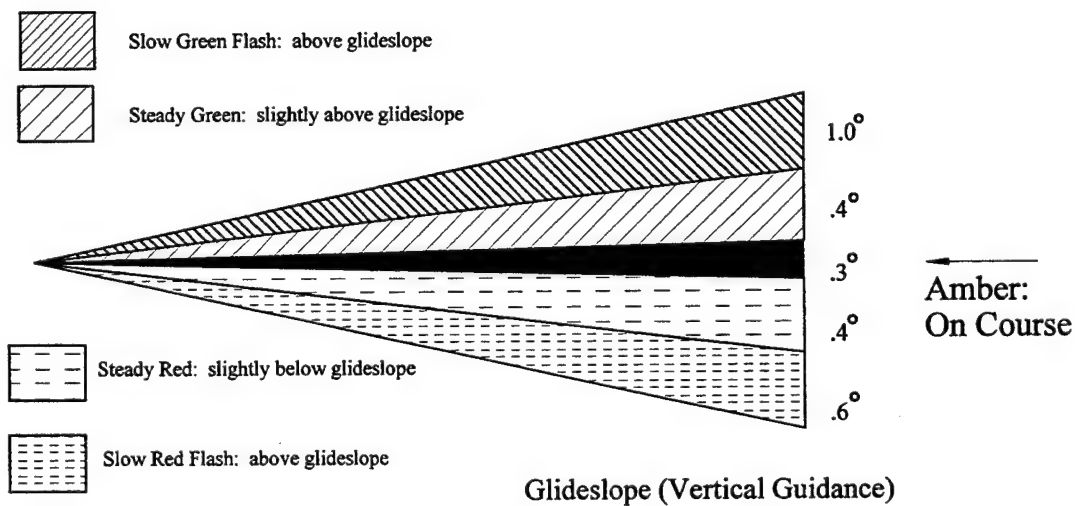
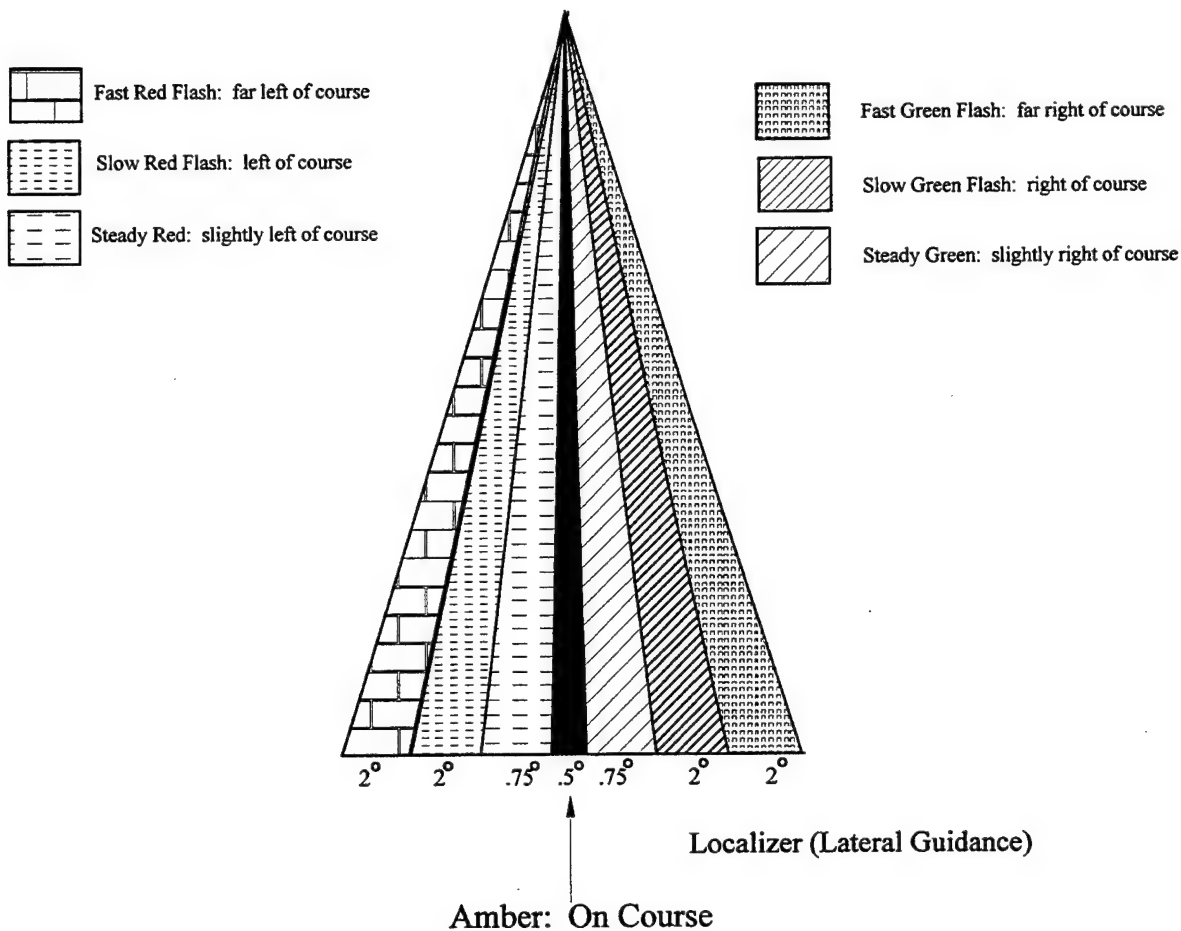


Figure 7 U.S. Navy Laser, Extended-Range Line-Up System

Note: Laser system uses narrow corridors of colored and pulsing light to provide precise line-up information to a range of 8 nm.

Some commercially available heliport lighting systems use 3 to 5 sequenced strobing lights to provide line-up information. Many more lighting systems have no dedicated lineup lighting components or sub-systems. In fact, most VFR heliport lighting systems in use today, do not have approach or line-up lights. A 1967 survey of civil operators, reported in reference 11, indicated that pilots obtained approach course information from other sources, i.e., training, charts, and radio communications. Although this survey is dated, sources of approach course information (non-visual) are still used by the majority of private operators. As the number of public heliports and heliport operations increase, visible line-up cues may become more cost effective. Certainly there is a need to standardize the presentation and distribution of such information to helicopter pilots.

7.2.2 Line-up Design Considerations

The heliport lighting designer can choose from a large number of line-up lighting components and subsystems that have varying footprints, accuracy, azimuth coverage, resolution, and sensitivity. Some heliport applications will not require the accuracy, resolution, and sensitivity of a typical fixed-wing application, but may require a more easily interpreted cue in order to reduce pilot workload. Some design considerations are summarized as follows:

- Testing of helicopter approaches to reduced landing minima (below 200 feet altitude) for 6-degree approaches revealed that lineup lights in front of the landing pad were below the cockpit cutoff angle and were not visible for much of the approach (reference 12). Consequently, extended line-up lines (positioned beyond the landing pad) have been recommended (reference 7).
- To be effective as a line-up cue, a solid line of lights should subtend a visual angle of not less than 19 minutes (0.32 degrees) (reference 13). For example, to discern a 0.20 nm lateral-line-up error (one-half the allowable airspace width at the MAWP on a non-precision GPS approach to a heliport) at a distance of 1 mile from the heliport, this requirement corresponds to a line of lights not less than 130 feet long.
- Vertical lines of light, paired with extended line-up lights (as shown in Figure 4) can reduce the length of lights needed to produce the required visual angle of 19 minutes. A prototype system (references 21 and 24) used a 20-foot vertical light pipe and 70 feet of ground lights. On a 6-degree glideslope, the 20-foot vertical light pipe appears to be approximately 190 feet long when projected into the horizontal plane. This produced an apparent light line length of 260 feet while using only 70 feet of ground space. Flight observations (reference 24) indicated that the prototype system was an effective line-up cue at ranges of 1 mi and greater.

7.3 GLIDESLOPE

7.3.1 Glideslope Cues

Under clear daylight conditions, a pilot can generally obtain sufficient glideslope cues from the airport or heliport environment. Flying a consistent glideslope requires the pilot to maintain a constant relative change in distance and altitude. This does not require a precise measurement of distance or altitude, but it requires the pilot to maintain a constant visual form ratio (the ratio of the visual angles of the length of the heliport to the width of the heliport, i.e. perspective). Maintaining this constant form ratio will cause the aircraft to touchdown at the center of the touchdown and lift-off surface (TLOF) or at the approach end of the runway.

Pilots are trained to perform landings "by the numbers", i.e. consistently, time after time. This ensures that the aircraft is flying near its optimum performance, and it ensures that all available cues will look the same, landing after landing. During clear daylight weather, sufficient natural cues exist to support safe and consistent operations. Many environments, both airports and heliports, have sufficient cues at night, in clear weather, to also support safe and consistent operations. Training, combined with consistent presentation of the cues, minimizes the chances of misinterpretation of the available distance and closure rate cues in degraded visual conditions. This also partially explains the higher frequency of mishaps involving unfamiliar airfields or seldom-used aircraft landing configurations or approach paths. Each of these situations causes the landing "picture" to look different.

Approach lighting systems, such as HALS, enhance some of these cues and are designed to provide height perception cues to the pilot. One can see that the length of the runway or approach lighting system will strongly affect the form ratio or perspective cue. Testing showed that pilots could effectively control glideslope when using the HALS system (reference 10). This same testing has also shown that a GSI reduces the pilot workload required for a safe landing.

Glideslope indicators of various combinations of angled colored and pulsing or flashing lights, have been used for years to provide the pilot with indications that the aircraft is either above, on, or below the desired glideslope. These cues require interpretation by the pilot. Tests in conjunction with the evaluation of HALS have shown a workload reduction but no significant reduction in glideslope error. Reductions in peak decelerations were greater (indicating a smoother deceleration to hover) when the GSI was used than with the HALS alone. These tests did show an improved performance and reduced workload with a GSI used in conjunction with HILS over HILS alone (reference 10).

The Navy has evaluated a GSI without approach lights in approaches to a basic IFR lighting system. The test (reference 15) showed that the GSI provided "essential and easily interpretable visual cues during the entire approach/recovery sequence." The pilots noted that a simple mental integration provided distance to go when altitude is known. On a 3-degree glideslope, adjusted for the shipboard placement of the GSI at 50 feet above the water and rounded to an easily remembered number, a 350-foot altitude equates to approximately 1 nm, 275 feet to $\frac{3}{4}$ nm, 200 feet to $\frac{1}{2}$ nm, and 125 ft to $\frac{1}{4}$ nm. By knowing the distance to touchdown, pilots can also

estimate whether or not closure rate is reasonable. Unless such a correlation with distance is required, the inherent accuracy of the GSI may not be important in a civil application.

A helicopter pilot on final approach to a heliport cannot maintain a constant glideslope by maintaining a constant speed and rate of descent. Adjustments in ground speed as the helicopter is decelerated affect glideslope control. The GSI has the advantage of providing specific visual feedback in a dynamic environment, (i.e. when ground speed, rate of descent and glideslope are all changing).

Glideslope control keeps the pilot flying "by the numbers." Too shallow an approach may expose the aircraft to obstacle hazards or create a noise problem. Too steep an approach may put the aircraft close to a performance limit. A consistent glideslope will ease the correct interpretation of available natural cues and reduce workload.

Many types of GSIs are available (table 2). They can be grouped into three general types (reference 16):

- 1) Color and pulse-coded signals: indicates deviation from "on-glideslope" with combinations of colors and pulse rates
- 2) Alignment of elements: indicates deviations from "on-glideslope" with the misalignment of objects or lights
- 3) Geometric patterns: indicates deviation from "on-glideslope" with perspective of standard geometric patterns such as squares, rectangles and circles. Pattern can be oriented to appear "correct" (no perspective effects) when on-glideslope or to use natural perspective as with HALS.

Type 1 and 2 GSI's can be designed to enhance interpretability and their sensitivity and resolution can be matched to the approach task. For example, consider the Helicopter Approach Path Indicator (HAPI) (figure 8) and the Navy's Fresnel Lens Optical Landing System (FLOLS) (figure 9). The FLOLS is designed to meet fixed-wing aircraft requirements for aircraft carrier landings. It is much more sensitive and precise than typical helicopter systems to provide the accuracy required for a carrier-arrested landing. The vertical maneuverability of the helicopter and the approach to a hover, vice landing, reduces the requirement for precise resolution. A system that is too precise increases the sensitivity and workload unnecessarily. The 12 degree beam of the HAPI in figure 8 contrasts with the 1.5 degree beam of the FLOLS of figure 9.

With type 3 GSI's, early testing showed little promise in geometric patterns oriented to show no perspective effects at the proper glideslope or approach angle. The relatively small size of heliports makes these geometric cues very weak, the sensitivity very low, and the wide variety of shapes and sizes of heliports possible makes misinterpretation more likely. The length of the HALS strengthens this cue by enlarging the heliport but, at the same time, limits its application. Even HALS benefited with reduced workload from the addition of a type 1 (color and pulse coded) GSI (reference 10).

Table 2 A Partial List of Various Glideslope Indicators

Abbreviation	Name	Type
VASI	Visual Approach Slope Indicator	1
AVASI	Abbreviated VASI	1
SAVASI	Simplified Abbreviated VASI	1
"T"-VASI	T-BAR VASI	1
"T"-VASI (abbreviated)	Abbreviated T-BAR VASI	1
GE Bi-Color	General Electric Bi-Color	1
PLASI I and II	Pulse Light Approach Slope Indicator	1
HELI-PLASI	Helicopter PLASI	1
MINI-PLASI	Miniature PLASI	1
HAPI	Helicopter Approach Path Indicator	1
HAPI-PLASI	Helicopter Approach Path Indicator – PLASI	1
VAPI I and II	Visual Approach Path Indicator	1
SGSI	Stabilized Glideslope Indicator	1
MOLS	Mirror Optical Landing System	1
FLOLS	Fresnel Lens Optical Landing System	1
ICOLS	Improved Carrier Optical Landing System	1
DLGI	Diode Laser Glideslope Indicator	1
PCOLA	Pulse Coded Optical Landing Aid	1
ROLA	Rainbow Optical Landing Aid	1
PVG	Precision Visual Glideslope	2
POMOLA	Poor Man's Optical Landing Aid	2
POLS	Portable Optical Landing Aid	2
BA-VASI	Bar Alignment VASI	2
PASI	Passive Approach Slope Indicator	2

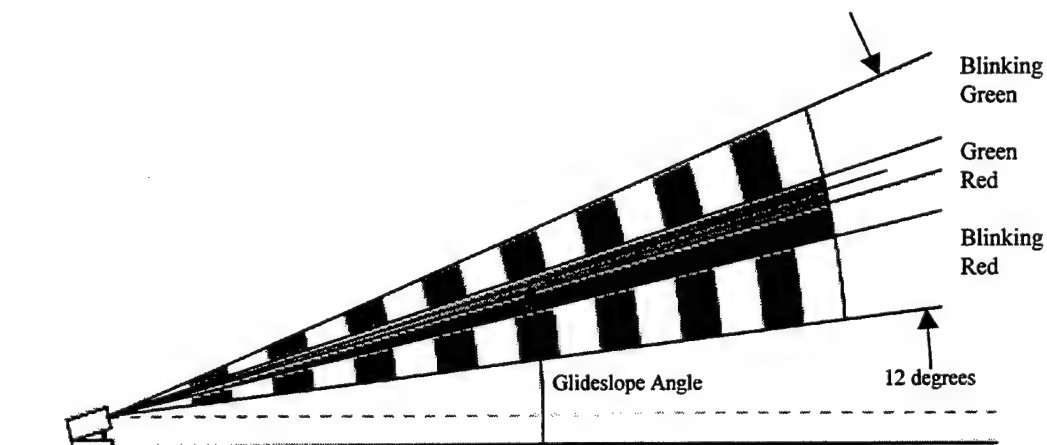


Figure 8 Helicopter Approach Path Indicator (HAPI)

Note: The HAPI uses a combination of colors and pulse codes to indicate direction and magnitude of glideslope error.

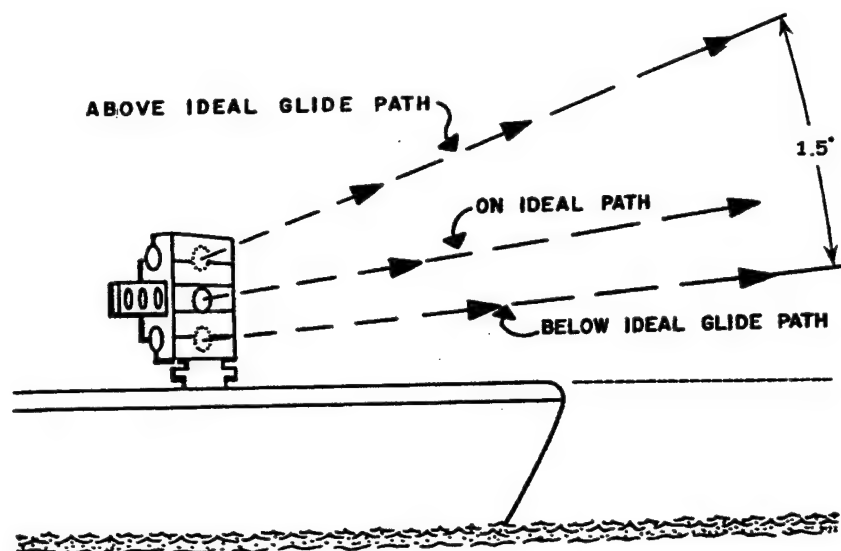


Figure 9 U.S. Navy Fresnel Lens Optical Landing System (FLOLS)

Consequently, the use of a type 1 or type 2 glideslope indicator is recommended, even when HALS is used. Table 2 lists some of the many types of GSIs developed in the past 40 years. Not all of these indicators were completely successful, but are listed to illustrate the many different ways that have been developed to present glideslope information. Many of these glideslopes were designed for operations to a runway; others were designed for special purpose operations such as shipboard or tactical military operations. Others have one or more deficiencies when used for helicopter operations at a heliport. Four glideslope designs are illustrated in figures 8 through 11.

7.3.2 Glideslope Design Considerations

Some glideslope design considerations are summarized as follows:

- The requirement for an augmented or enhanced glideslope cue is site-specific and operation-specific.
- GSI interpretability and sensitivity have a large effect on pilot workload.
- Type 2 GSI's (alignment of elements) have large "footprints" requiring more space than type 1 GSI's (color and pulsed-coded signals).
- Point source GSI's are more difficult to acquire and reacquire visually than other GSI's. (This can be exacerbated in a city environment with many other point light sources in the surrounding area.
- GSI's can incorporate warnings that signal excessive glideslope errors.
- Point source GSI's should be aligned to allow the pilot to fly under or over the guidance beam in close proximity to the helipad. Inside approximately 800 to 1,000 feet from the heliport (80 to 100 feet in altitude on a 6 degree approach), pilots need to shift their scan to take in all the natural cues available (closure rate, altitude and distance) in order to

transition safely to a hover. If the GSI is aligned to guide the pilot all the way to the hover and the intensity is set to support initial acquisition, the lighting intensity will be excessive when the pilot approaches a hover near the helipad.

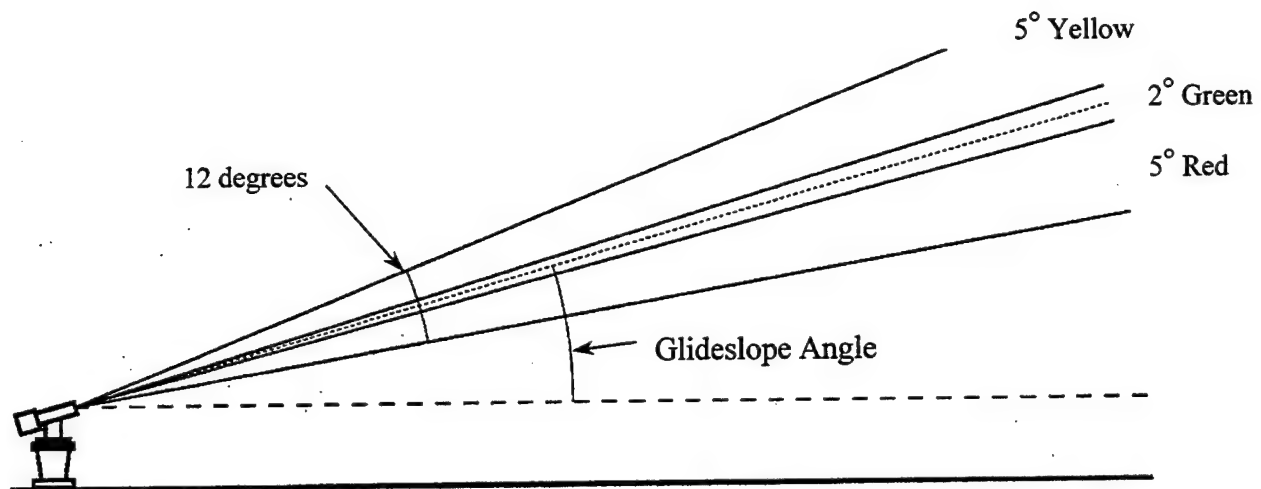


Figure 10 Three-Color Glideslope Indicator.

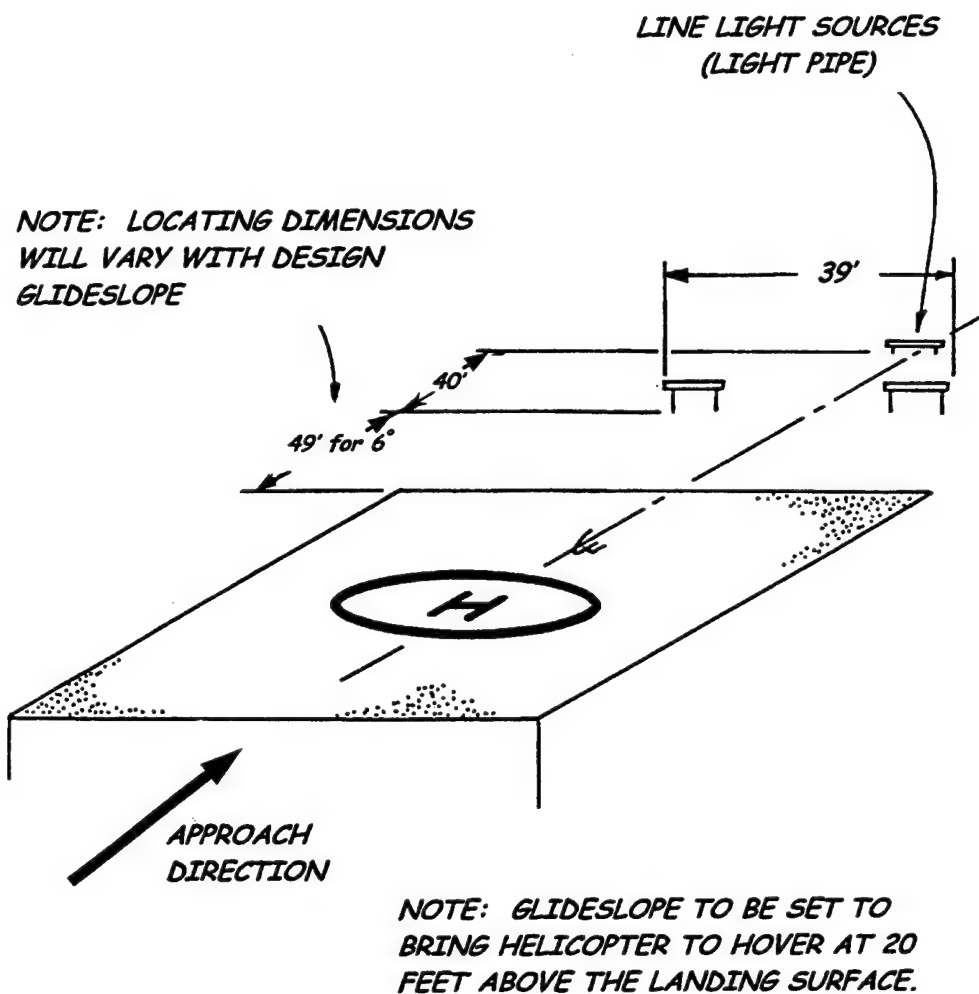
Note: The Navy changed the order of the colors to green (high), yellow (on glideslope), red (low) to avoid a yellow indication as the display transitions from green to red (Reference 16). A yellow to red transition is seen as orange and can be used to increase the effective resolution of the display by flying the orange instead of the yellow.

7.4 HORIZON

7.4.1 Horizon Cues

In the absence of a natural horizon, (something often encountered in approaches to very dark areas), the heliport lighting system horizon cue may become the most critical lighting cue. With no natural cue available, the pilot can easily misinterpret changes in contrast, caused by a shoreline or mountain range or distant city lights, as an horizon. In an urban environment, the large number of lights provides a relatively high ambient light level and a strong natural horizon, even under a solid overcast. Additional cues can be interpreted from both the vertical and horizontal surfaces of structures (which are often well-lit). The relative strength of these urban horizon cues should be evaluated in conditions of reduced visibility.

Artificial horizon cues can be combined with other lighting components. Approach lighting systems typically use rows of lights perpendicular to the approach path to enhance the visibility (more light) of the line-up cue and to provide a horizon cue. The University of Tennessee Space Institute (UTSI) has suggested (reference 7) that a properly sized GSI consisting of three horizontal lines of light could also provide a horizon cue (figure 11). Perimeter light extensions and wing bars can provide the horizon cue in addition to enhancing optical expansion rate cues (see section 7.5.1).



INDICATIONS:

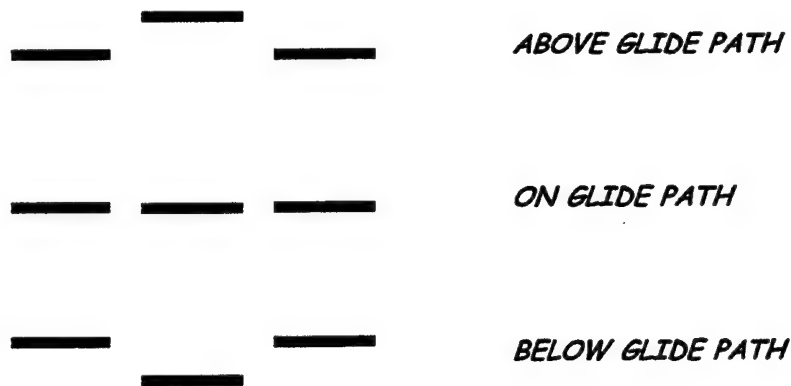


Figure 11 Lower Cost "Alignment of Elements" Glideslope Indicator

7.4.2 Horizon Design Considerations

Some design considerations are summarized below:

- To be effective as an horizon cue, a solid line of lights should subtend a visual angle of 132 minutes (reference 13). This corresponds to a 101-foot line of lights perpendicular to the approach path for a ½-mi final.
- Research is required to determine similar “rules of thumb” for the required length of vertical lines of light to be effective as artificial horizon cues.
- The minimum ambient light level that ensures adequate horizon cues in an urban environment should be determined, if possible.
- It is important to ensure that the horizon cue is perpendicular to the line-up cues in order to avoid possible spatial disorientation in reduced visibility.
- Possible false horizon cues should be identified and taken into consideration when designing a horizon cue.
- Lighting fixtures should be located so as not to introduce an obstruction hazard.

7.5 CLOSURE RATE

Closure rate becomes more difficult to determine in conditions other than clear daylight. In attempting to compensate for lack of closure rate information, pilots instinctively slow down. If the pilot slows down too much too early in the approach, the resulting increase in power required for level flight (on the back side of the power curve) can cause a significant, if not catastrophic, loss of altitude. Equally dangerous, if the pilot does not slow down early enough in the approach, a last minute deceleration may require such an extreme pitch up attitude that the landing area may be blocked from the pilot's view.

Closure rate is defined as the speed divided by the distance to go (reference 17). Depth perception, the ability to judge distance, at distances greater than approximately 20 feet, is determined from seven cues (reference 14):

- Familiarity with known objects
- Interposition of objects
- Perspective
- Motion parallax (relative apparent speed, far objects move more slowly)
- Increasing and decreasing object size and detail
- Color and haze in the distance (Objects far distant usually appear somewhat muted in color.)
- Lights and shadows

In addition to the changing depth perception cues above, there are three important optical cues that a pilot can use to control speed during the visual segment of an IFR approach to a hover. These are discussed in the following three sections.

7.5.1 Optical Expansion Rate

Optical expansion rate (reference 17) is the relative rate of growth in optical size of the landing pad. This is proportional to the closure rate of the helicopter but independent of altitude. As the helicopter approaches the landing site, the landing site appears to expand in size as the optical angle increases (figure 12). The angle increases more and more per unit distance traveled toward the heliport as the distance decreases. As a helicopter approaches the heliport at a constant velocity, the optical expansion rate will continue to increase. Therefore, if the pilot slows the helicopter to maintain the optical expansion rate below a threshold value, the helicopter will slow to a stop at the center of the pad. The visual effect is similar to the "ground rush" at the bottom of an autorotation that an experienced helicopter pilot uses to cue the initiation of a flare. Lowering the threshold value will yield a more gradual deceleration.

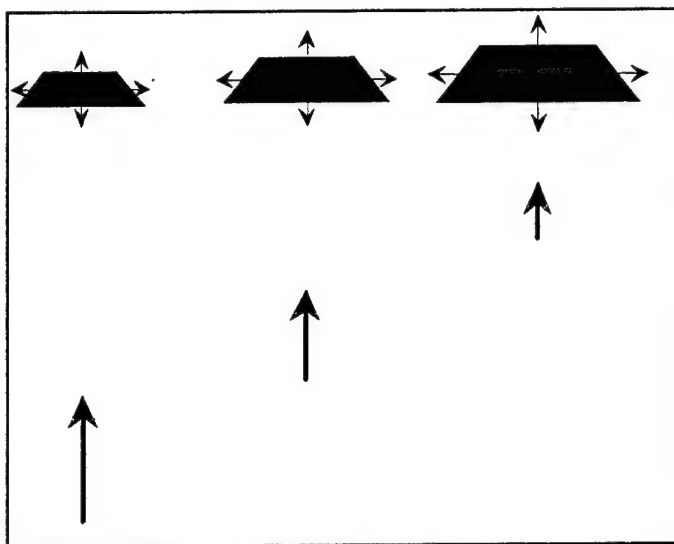


Figure 12. Optical Expansion Rate (reference 17)

Note: In order to maintain the optical expansion rate below a threshold value (set by experience and training) the pilot must slow the helicopter as it nears the heliport.

This cue is typically provided by landing pad perimeter lights and extensions (figure 13), but Navy testing (reference 15) showed no adverse effects associated with the absence of red deck edge (perimeter) lights. Navy pilots reported that the major closure rate cues (from 1/8 nm to one or two rotor diameters from pad) were provided by deck surface floodlights and hangar surface floodlights on single spot ships (No approach lights or wing bars are available for shipboard approaches). Tests were conducted with deck edge lights on with no deck surface lights and the reverse. From this test, it appears that deck surface floodlights that illuminate the entire surface provide stronger closure rate cues than does a simple outline of the surface. A possible explanation of this test result is the importance of object size and detail to proper judgement of distance. In clear daylight conditions, decreasing range allows the eye to define increasing detail. If the increasing glare of point source lights obscures or fails to illuminate the detail, the eye can be misled. Sufficient surface illumination will provide the eye with the anticipated increasing detail. Deck surface lights also have other advantages for the precision hover task, as will be discussed later.

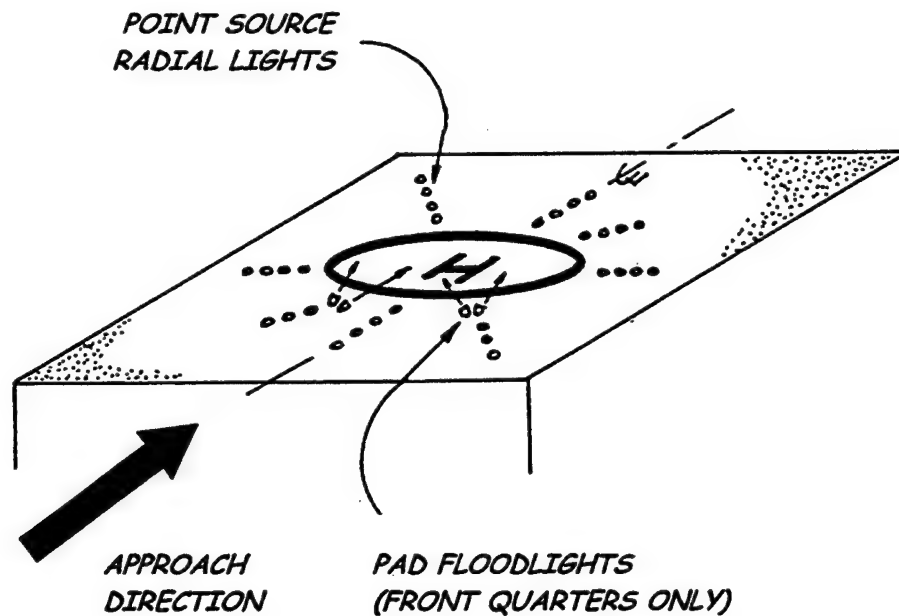


Figure 13 Heliport Surface Lighting

Note: Perimeter lights and point light sources in a radial layout enhance the optical expansion rate cue.

7.5.2 Optical Flow Rate

Optical flow rate (reference 17) equals the angular flow velocity of surface elements in any one area of the field of view and is proportional to ground speed divided by the distance to the viewed surface. It can best be described as the angular velocity of a light passing from the front to the back of the chin bubble. One can change the optical flow rate by changing the distance to the object, (e.g., as a passing train is approached, the cars appear to pass by more quickly). If the helicopter descends and maintains a constant ground speed, lights and terrain features will appear to increase in speed, (i.e. they will flow by faster). As with the optical expansion rate, if the pilot does not allow this apparent speed to increase above a threshold value, the helicopter will be slowed to a stop at the pad. Again, as with the optical expansion rate, a higher threshold value will delay more of the total deceleration until the helicopter is closer to the pad, and a lower value will result in a more gradual deceleration.

Because changing the point on the ground being viewed also changes optical flow rate, it is a difficult cue to interpret and to fly precisely. The pilot learns by experience the critical threshold optical flow rate that results in a reasonable speed on arrival at the pad. The cue becomes stronger as the field of view where terrain and lights are visible becomes larger. Passing clouds or variable visibility may increase the difficulty in interpretation. Rough terrain, non-level terrain, or varying building heights may also increase the difficulty of this interpretation.

Optical flow rate will provide closure rate cues if there is something to see passing below and behind the helicopter on the final approach. In a very dark environment, an approach lighting system with a long string of lights, such as HALS, can provide an optical flow rate cue that reduces pilot workload and improves pilot control of closure rate. In an urban environment, the higher ambient light levels may illuminate terrain features sufficiently to be visible to the pilot along with street and building lights. Together, these will also provide an optical flow rate cue that will aid in closure rate control. Again, pilot experience is used to maintain the optical flow rate or apparent speed below some critical value.

7.5.3 Optical Edge Rate

Optical edge rate has been studied by the National Aeronautics and Space Administration (NASA) in a simulator study at their Ames Research Center (reference 17). Optical edge rate is defined as “the frequency at which optical elements pass through some visual locale (e.g., the lower portion of the windscreen).” The best example is the white lines passing out of view in front of an automobile moving along a well-marked road. In flight over lights with constant spacing, optical edge rate will be directly proportional to ground speed. If the spacing between the lights is decreased in proportion to distance to the landing pad, maintaining a constant optical edge rate will result in a deceleration to zero ground speed. The NASA study (reference 17) showed some improvement in closure rate control when the spacing between the lights was decreased in a proportional manner.

Research has shown that edge rate and flow rate have roughly equal impact on the perception of self-speed (reference 18). Also, faster initial flow rates (higher ground speed at the start of the approach) have a negative affect on the pilot’s ability to judge decelerations (references 17 and 18). This implies that slower speeds at the DWP may improve the pilot’s performance in controlling closure rate.

7.5.4 Use of a Glideslope Indicator to Interpret Closure Rate Cues

It should be noted that these closure rate cues are “natural cues”, that is, they do not require the pilot to interpret them as required by a ground speed digital readout. Even though they are natural cues, NASA Ames testing (reference 17) revealed that there was improvement both with practice and with explanation of how these cues worked. Even though a GSI was not used, these tests were carefully configured to consistently cue the start of each descent (the beginning of the glideslope). This consistency in glideslope allowed the pilot to build an experience base from which to compare future approaches. Deviations from this experience base cue the pilot on closure rate corrections.

The GSI adds consistency to the approach – consistency and repeatability – so that each approach looks the same. The presence of a GSI removes one axis of freedom from the approach, which means that a change in optical flow rate, when “on glideslope,” can be correctly interpreted as an indication of a closure rate error not an altitude error. This allows the pilot to build the experience base he needs in order to use the optical flow rate cues that he does get from the ambient lighting conditions, or from the approach lighting system. Performance should improve as experience develops. As discussed earlier, the use of a GSI in the HALS tests (reference 10) resulted in a larger decrease in peak decelerations than did the use of HALS alone.

In order to be effective in this role, however, the GSI must be easily acquired (visually) and easily interpreted. An overly sensitive system may create such a high workload that closure rate cues may be missed as the pilot devotes more of his concentration on the GSI.

7.5.5 Alternative Closure Rate Cues

In addition to the three natural closure rate cues that have been discussed, there are other means to pass to the pilot the information necessary to calculate closure rate. The pilot can acquire the range and speed information required to judge closure rate from cockpit displays (if ground speed, not air speed is displayed). As the helicopter gets closer to the landing pad, this requirement to look inside the cockpit for the required information can result in a significant increase in workload. Due to changing crab and pitch angles, the relative position of the cockpit displays changes and the pilot is forced to locate the appropriate displays (sometimes two different displays), acquire and assimilate the information, and then transition back to an outside scan of a heliport with a changed relative position. Subtle changes in closure rate cues and critical trend information may be missed while the pilot's attention is diverted. Navy flight crews employ the second pilot as a voice relay of range and speed information to allow the pilot to maintain his scan outside the cockpit.

"Range gates" or lights that are shielded to become visible at specified ranges from the landing pad can be used to cue the pilot to check his ground speed against a preplanned deceleration profile at specific ranges from the point of intended landing. These range gates have the potential to reduce the number of times the pilot must change his scan during final phases of the approach and will ease the interpretation of the range and speed information since a "target" speed is available for that specific range. The range gates can be color coded to indicate actual range.

7.5.6 Closure Rate Design Considerations

Some design considerations follow:

- Closure rate is the most difficult cue to augment or enhance.
- Increased initial speed adversely affects pilot performance of the deceleration task., i.e., slower initial speeds reduce workload and cue requirements.
- Training, experience, and glideslope consistency improve pilot interpretation of closure rate cues.
- High ambient light levels and city lights provide improved optical flow rate visual cues to the pilot.
- Pilot deceleration performance over long rows of lights (HALS) can be improved and workload can be reduced with the addition of a GSI.
- GSI's that are difficult to visually acquire and those that are overly sensitive can inhibit the pilot's ability to perceive the natural closure rate and distance cues.
- Glare can reduce the pilot's ability to perceive closure rate cues.
- Procedures and crew coordination can reduce workload and closure rate cues required.
- A well defined perimeter can enhance the optical expansion rate cue.

- Widely spaced lighting elements at the edges of the FATO can enhance the optical expansion rate cue.

7.6 TOUCHDOWN

7.6.1 Touchdown Cues

In the lighting configurations shown in figures 13 and 14, the optical or texture elements are lights. In daylight, the texture elements could be rows of trees or telephone poles. All these are classified as “macrotexture.” Macrotexture, in the form of point source lights, has been used to provide cues to pilots (both fixed and rotary wing) on constant speed and constant rate of descent approaches to runways. These lights also provide the flare cues as the pilot approaches the touchdown spot. The runway environment has the advantage of long lines of lights that provide multiple texture elements to the pilot at all times. Smaller sets of lights in a heliport or landing zone environment do not provide all the optical cues discussed above and, due to size constraints, provide far fewer texture elements. Additionally, the pilots are required to decelerate and descend to a hover, a much more precise task than an approach to a runway.

Fine grained detail such as blades of grass, the roughness of nonskid surfaces, or cracks in the landing surface are classified as “microtexture.” Lack of fine-grained detail can result in a substantial increase in the workload required simply to control the helicopter in a hover or in low speed flight close to the surface (reference 19). Conditions that lead to a lack of microtexture include a smooth featureless surface, (e.g. still or dark water, poor visibility conditions, and/or an unlit surface).

Note: The perimeter lights enhance the optical expansion rate cue.

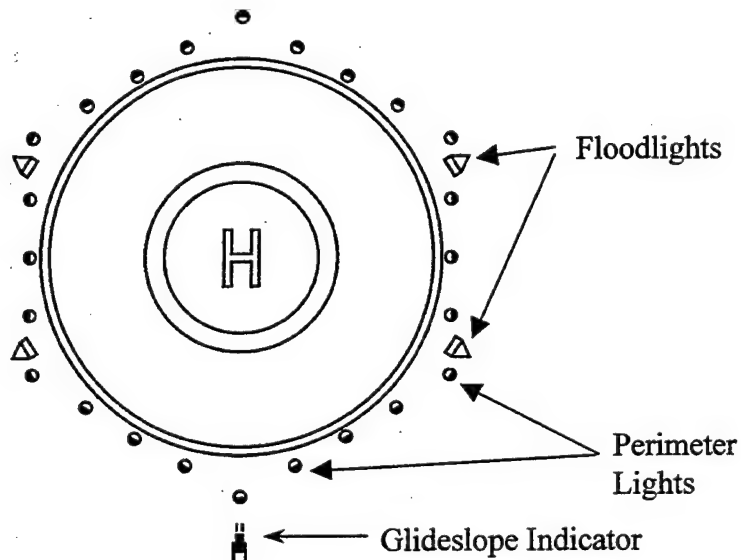


Figure 14 Heliport Perimeter Surface Lighting

Pilot workload can be reduced with increased attitude stabilization in the helicopter or by lighting the surface and surrounding obstacles in such a manner that microtexture can be seen by the pilot, or with a combination of both.

Touchdown cues are sometimes thought of as simply answering a question of "Where do I land?" Based on the above discussion on macro and microtexture, touchdown cues will include the cues required to perform a precise hover and then touchdown. At some heliports, it may also include hover taxi or ground taxi to a parking space.

Military lighting systems for unprepared sites are designed to provide a safe landing environment with the minimum number of lights and equipment, often keeping the systems man-portable. Such systems use 3 to 4 point source lights arranged in an inverted "T", "Y", or "V" and provide macrotexture only (figure 15). Pilots are instructed to maintain at least two lights in their field of view at all times in order to avoid fixation and autokinesis effects. Light spacing has to be greater to support higher hover heights. Training and proficiency requirements can compensate for reduced visual cues. Pilots are also trained to avoid hovering in conditions where "whiteout" due to snow or "brownout" due to sand is likely. Both cases eliminate microtexture and in some cases macrotexture. Pilots may be able to use landing lights and spotlights to ease the hover task. Systems using bright point source lights can actually eliminate microtexture with glare and excessive contrast. The designers of such systems may rely on pilot use of landing lights to provide illumination of microtexture. Many helicopters, however, are equipped with fixed landing lights that do not illuminate the landing area when the helicopter is flared while transitioning to a hover.

Point source lights, used to outline the perimeter of a landing pad, do not adequately illuminate the texture of the landing surface. If point source lights are made bright enough to provide useful approach cues, they are too bright to be useful as a hover aid. The brightness of the point source prevents the pilot from seeing the surrounding texture and leaves an annoying and often disorienting "after image" in the pilot's view. Radio control of lighting intensity is often used to mitigate this problem although it adds to pilot workload. (Cold cathode lights have also shown promise in solving this problem).

VFR and current IFR lighting provide perimeter lights, perimeter light extensions, and overhead floodlights. As previously discussed, Navy ships also use deck surface and hangar face floodlights. The value of microtexture is already evident in some design guides. A 1984 offshore pad lighting design guide (reference 20) from the Louisiana Department of Transportation points out that "Yellow lights have the advantage of lighting the deck area, while blue lights can be seen from greater distances." It therefore calls for a minimum of 8 perimeter lights alternating yellow and blue, one at each corner and one in the middle of each side. It goes on to state that, "A slight roughness of the surface will help the pilot's depth perception."

In many cases, both civil and military, overhead floodlights are turned off during the approach to eliminate glare in the cockpit and are used only for maintenance. The deck surface and hangar face lights avoid this problem by lighting surfaces with lights oriented parallel to the surface. This

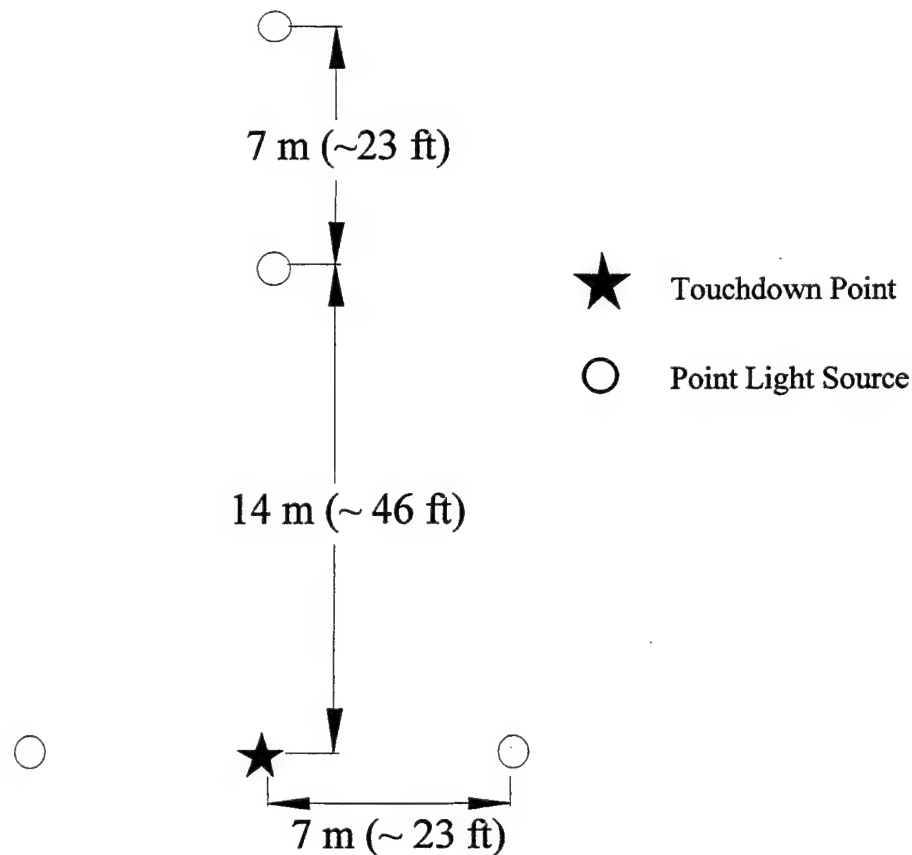


Figure 15 Tactical Lighting System

Note: Tactical lighting systems use a few point source lights to provide macrotexture to the pilot. These systems were designed to provide the minimum cues necessary for safe operations. Training, proficiency and dual pilot crews are relied on to compensate for any inadequacy in the cues provided by the lighting.

requires more lights and adds an obstruction to the pad edge. Surface floodlights are also in use at many civil heliports. These fixtures must be carefully sized, shielded, and placed in order to avoid creating a glare and/or an obstacle hazard. (See figures 14, 15 and 16). Surface floodlights should be isolated on a separate lighting circuit that enables the dimming of these lights to match and blend with the other types of lighting in use. The Heliport Design Advisory Circular (reference 3) recommends maximum height of lighting fixtures based on the distance from the TLOF. The surrounding land may require grading to allow installation of larger lighting fixtures.

In unique cases where a very precise hover is required (usually military), precision hover aids of varying complexity have been developed to aid pilots in confined area landings. Most of these have proven less than fully effective and precise positioning, when required, is usually aided by ground personnel.

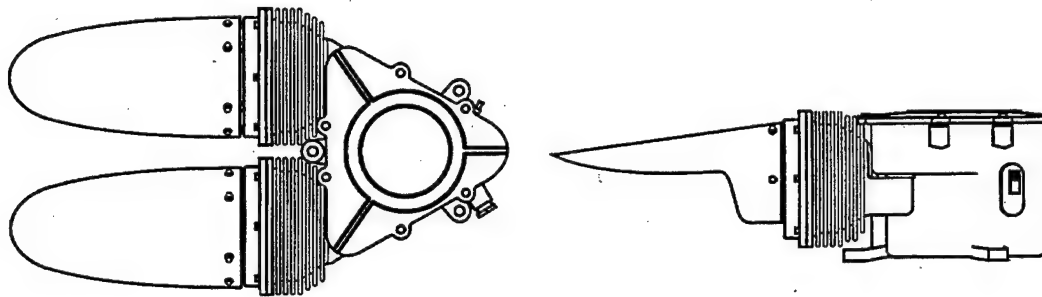


Figure 16 Floodlights

Note: floodlights are shielded to direct more light along the surface of a structure or landing pad and to prevent direct viewing of the lights by the pilot.

7.6.2 Touchdown Design Considerations

Some design considerations follow:

- Illumination of the surface microtexture provides important cues necessary to support the transition to a hover and precise hover positioning and landing.
- Illumination of vertical surfaces also provides microtexture cues to the pilot.
- Surface illumination can be provided by shielded surface mounted flood lights (shielded from direct view by the pilot) and by newer lighting technologies such as light pipes and cold cathode lights (diffused light sources).
- Care must be taken not to add obstructions to the landing environment when installing surface lighting.

8.0 HELIPORT LIGHTING SYSTEMS

The goal of the proposed design methodology is to use the lighting system components described above (and others) in combination with the heliport environment to provide the helicopter pilot with the cues required to safely and consistently land and take-off. It is therefore impossible to address every conceivable combination of the components and subsystems previously described.

This section will describe a few heliport lighting systems that have been installed or are being considered for installation. These heliport lighting systems use both conventional lighting components and some of the newer components and subsystem configurations designed or identified during this research effort.

8.1 HILS and HALS

These lighting system designs will be addressed with the benefit of hindsight and the testing conducted by the FAA (reference 10). The combination of these systems was designed to provide the following cues: "... visual information on horizontal path alignment, roll guidance, deceleration or rate-of-closure determination, and height perception for precision approaches" (reference 2). The test environment at the FAA Technical Center heliport has very low ambient light levels and degraded visibilities were simulated with special vision restricting goggles. A complete heliport lighting system composed of HILS and HALS with enhanced perimeter lighting and centerline lighting is shown in figure 17.

Acquisition. The HALS system puts lights 1,000 feet closer to the DWP or MAWP. The system provides early acquisition of the landing environment and therefore qualifies for a $\frac{1}{4}$ mi visibility credit. Identification of the heliport is provided by the navigation system for instrument approaches. In better visibility, the unique and regular layout of HALS and HILS together should be easily recognizable in all likely heliport environments. Light settings that produce the best acquisition cues are too bright for other phases of the approach, however.

Line-up. The length of the system provides a strong line-up cue, although some of the lights may be behind a helicopter on an instrument approach to 100 feet altitude on a 6 degree glideslope. The cue is easily interpreted, has no lag, and provides 180 degree coverage. Again, light settings that provide long range line-up cues will be too bright in close.

Glideslope. The length of the HALS system provides a glideslope cue that is strong enough to allow pilots to fly accurate glideslopes. The glideslope angle is defined by the distance from the heliport at the initiation of the descent and the sensitivity of the perspective cue provided is slight. Based on pilot reports that the workload is reduced with the addition of a glideslope indicator (reference 10), the HALS glideslope cue is harder to interpret.

Closure Rate. Testing established that the closure rate cues provided by HALS are adequate to decelerate from 90 knots in the last 2,500 feet to the heliport in low ambient lighting conditions.

Horizon. The horizontal rows of the HALS combined with the wing extensions of the HILS provide an horizon cue from the DWP to touchdown.

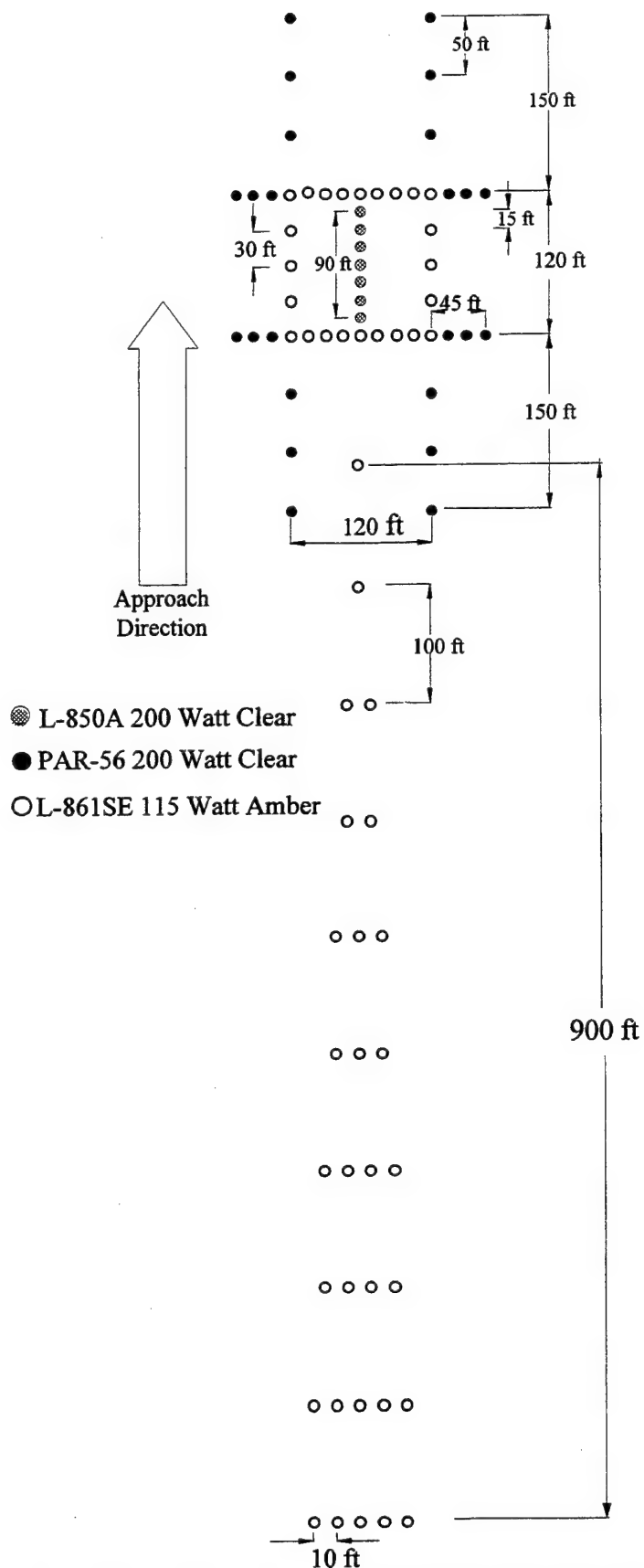


Figure 17 HILS and HALS with Perimeter Light Enhancement and Optional Centerline Lights

Touchdown. When the point light sources are set at intensities to support the start of an approach, they are too bright in close to the heliport. Radio-controlled lighting will allow the pilot to dim the lights (increasing workload) as the heliport is approached, but the point source lights provide little illumination of the landing surface.

8.2 OPERATION HELI-STAR

The second lighting design considered is a prototype system that was developed and tested at the University of Tennessee Space Institute. Initial tests were sufficiently promising that the FAA made the decision to continue the evaluation in the controlled operational environment of Operation Heli-STAR, a demonstration helicopter transportation system established in Atlanta, GA during the 1996 Olympics (reference 21).

The prototype system used a 20-foot light pipe, green cold-cathode lights, and electroluminescent panels. A semi-permanent installation, suitable for re-use, was built and installed at a temporary heliport at a commercial site. The design process was atypical in that nine temporary heliports were evaluated to find the best location to perform an evaluation of an existing lighting system. The process did, however, match site requirements to lighting system cue enhancements. The prototype system, detailed in figure 18, enhances the acquisition, line-up, closure rate, and touchdown cues. The site chosen for the evaluation allowed a single approach to a landing spot with obstacles on all sides. Ambient light levels were high in the city environment, and the same surrounding lights made conventional amber heliport lighting difficult to identify. During the three-week operational period, the weather was generally clear with good visibility. No flights were flown to the demonstration heliport in low visibility conditions. Therefore, all observations from this evaluation only apply to clear weather conditions.

Acquisition. The prototype system provides easy acquisition of the landing environment at ranges out to 20 miles in clear weather. Identification of the heliport is provided by the unique color (green) and the unique character of the cold cathode lights and light pipe. The same intensity setting that provides acquisition cues out to 20 miles does not adversely affect pilot vision in a hover over the pad. No dimming is required.

Line-up. The short length of the system is enhanced by the vertically mounted light pipe, providing a strong, easily interpreted line-up cue.

Glideslope. A VASI was added to provide the required glideslope cues. The point source glideslope indicator did not adversely affect the control of closure rate. More than eight lights are required to adequately define a circle that can be used to provide form ratio or perspective. The four lights at 45, 135, 225, and 315 degrees relative formed a box when the system was viewed on the six degree glideslope. The four lights at 0, 90, 180, and 270 degrees attached themselves visually to the line-up and wing bars of the lighting system. The circular pattern could not be discerned until approximately ½ mile to the heliport.

Closure Rate. In clear weather, the high ambient light levels and the well-defined landing zone provided adequate closure rate cues.

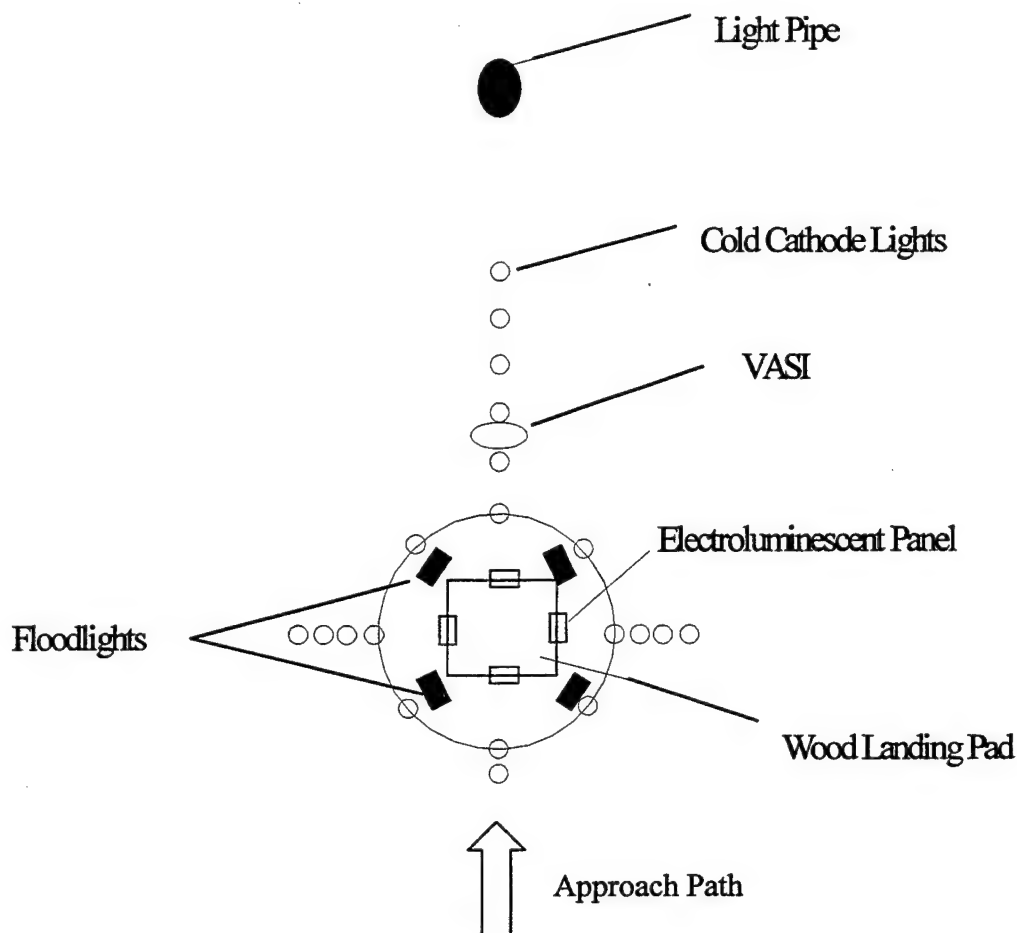


Figure 18 Prototype Lighting System Installed at the NationsBank Southside Heliport in Atlanta

Touchdown. In clear weather, the cold cathode lights provided ample translational cues to support the transition to a hover, the hover itself, and landing tasks, without the use of additional floodlights.

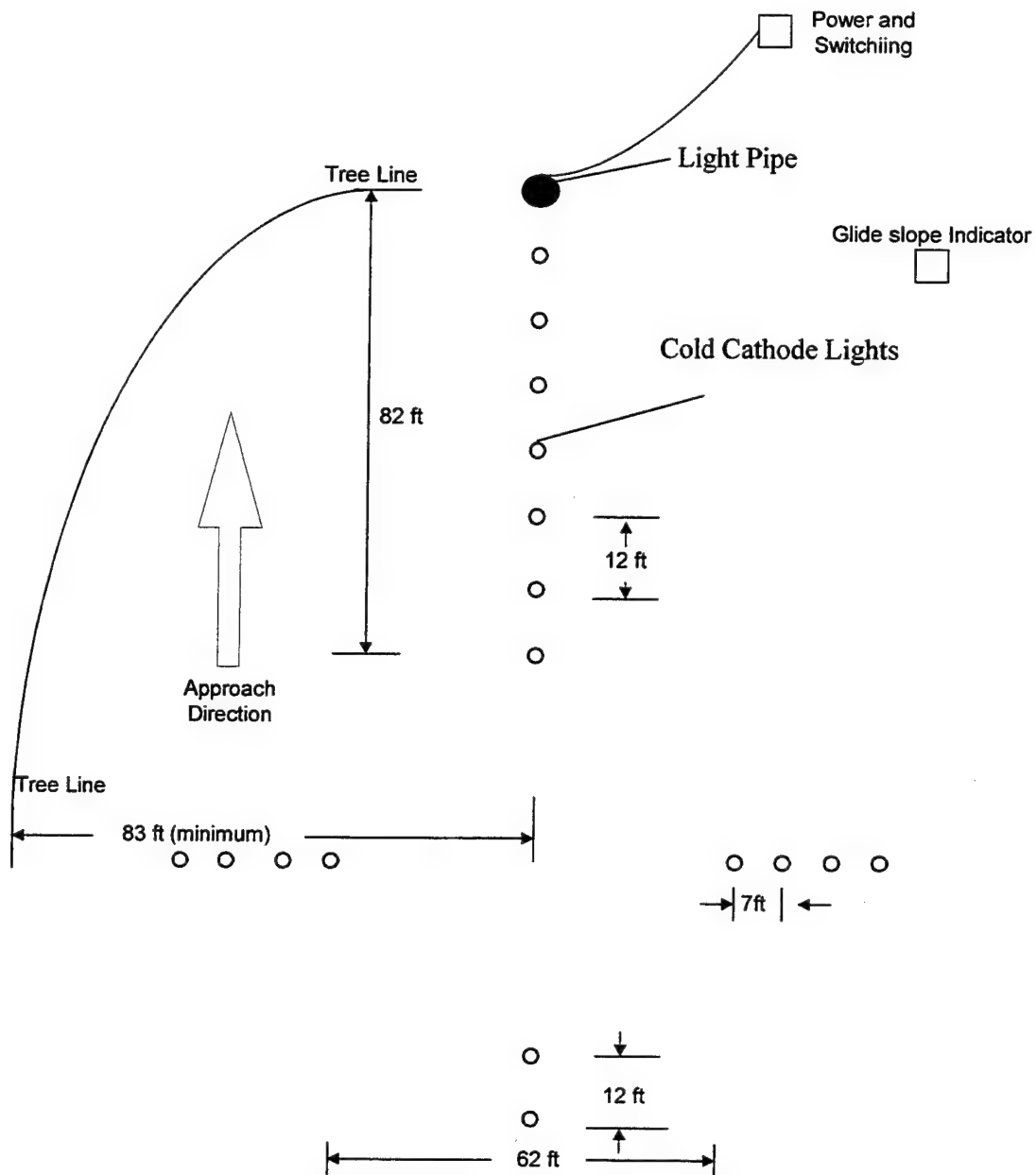
In clear weather, the prototype system provided all the same cues as the HILS and HALS combination with the exception of the early acquisition cue. It should also be noted that some of the required cues at this particular location were adequate without augmentation or enhancement by the lighting system. The same system, located in the darker environment at the FAA Technical Center where HALS was tested, would probably require additional components to provide all the required cues.

8.3 A DESIGN CASE STUDY

The third lighting design considered is depicted in figure 19. This system was designed as part of a case study that exercised the design methodology developed in this report. The site chosen for the heliport was located in a metropolitan area on a gently sloping grass-covered field surrounded by tall trees. The ambient light level provided by surrounding city lights was very high, especially when the sky was overcast. Pilots were interviewed regarding the challenging aspects of the approach and confirmed the results of the site survey. The site was difficult to acquire, even with a rotating heliport beacon, and was easily lost if the pilot looked away. Line-up was critical due to very tall trees close to both sides of the approach path. Glideslope was also critical due to the tall trees. Closure rate and attitude control (horizon) were not a problem for the pilots in the well-lit city environment. Transition to a hover and hover were aided by the use of landing lights and floodlights that were located at the base of the trees in front of the landing zone (pointing away from the approaching helicopter). Landing and parking areas were separate from the FATO.

The system designed to support operations at this heliport, figure 19, enhances the required cues identified by the pilots and the site survey. The system has not been built, but the design closely resembles the Heli-STAR design. The one exception is the touchdown cue. Since the ambient light levels are quite high, and closure rate cues are adequate, the number of lights surrounding the center of the FATO was reduced.

Another design constraint involves the placement of the GSI. It is located on the right side of the FATO to increase the visibility to the command pilot and to decrease the glare visible to the pilot when in a hover over the center of the FATO. The tall trees on all sides of the FATO prevent the location of the GSI on the approach side of the FATO where it will not be visible to the pilot in a hover. GSI intensities required to support acquisition of the signal at the start of the approach typically are a discomfort to a pilot in a hover directly in front of the GSI. To minimize this glare problem at this site, the only practical option is to remotely activate the GSI to allow the pilot to turn it off close to the heliport.



Note: Heliport and lighting designed to support a Sikorsky S-61 (overall length: 79 ft; rotor diam: 62 ft)

Figure 19 Prototype Heliport Lighting Design Using the Study Methodology

9.0 CONCLUSIONS AND RECOMMENDATIONS

Specific design considerations were included in the discussion of each of the required lighting cues. The following is a list of conclusions and recommendations that address the continued development of heliport lighting systems for instrument approaches.

- 9.1 To some extent, heliport lighting designs are site and operations specific. One design will not work for all situations. Some manageable grouping of possible heliport types appears appropriate. Three types are proposed here: rooftop, ground-level/off-airport, and ground-level/on-airport. Guidelines should be developed to assist the designer in developing one or more cost-effective systems tailored for each of these groups.
- 9.2 Standardization is even more important when pilots are faced with a variety of lighting designs. System components should follow a standard convention.
- 9.3 The cues required for a safe instrument approach are identified: acquisition, line-up, glideslope, horizon, closure rate, and touchdown.
- 9.4 The FAA should investigate alternative early-acquisition lighting systems. Currently only HALS qualifies for a lighting credit and HALS is not suitable for installation at many locations. Lead-in lights that can be installed on top of buildings and above streets or highways are potential solutions.
- 9.5 The Ground-level/on-airport category is an important grouping in that it includes the emerging requirement for a lighting system to support vertical flight instrument approaches and departures that do not conflict with simultaneous airplane operations.
- 9.6 It is possible that not all cues will require augmentation at all sites. Natural cues may be sufficient at some sites. This determination will require careful analysis of the minimum requirements for each phase of the approach. A flight inspection process, flown in conjunction with the inspection of the instrument approach, would be required to certify the resulting lighting system. Before the FAA could adopt this policy, some practical and objective means must be found to define and determine when augmentation of a certain cue is not required at a particular site.
- 9.7 One potential method for the determining the adequacy of visual cues might be through the measurement of pilot performance of standardized tasks. Pilots are notoriously poor judges of the adequacy of visual cues. This has been demonstrated by weather-related accident rates and backed up by flight testing (reference 22). The process of accurately measuring visual cues has been well documented in ADS-33D, Handling Qualities Requirements for Military Rotorcraft (reference 23). The evaluation maneuvers are simple tasks that measure the required workload in degraded visual conditions and compare it to clear conditions. The maneuvers detailed in ADS-33D might be modified to evaluate the adequacy of the cues available at each site. Testing would be required to determine how evaluation maneuvers could be incorporated into the evaluation process.

- 9.8 Explore the use of a unique color or light characteristics to differentiate large heliports and vertiports from small airports as well as to improve acquisition cues.
- 9.9 The following methodology for developing standard heliport lighting systems for use at different types of heliports (see 9.1) is proposed. Testing at a variety of heliports in a variety of environments would be necessary to determine if this approach is safe and effective in all cases.
- a. Conduct a site survey.
 1. Define the task to include the operating environment and its constraints.
 2. Define the information required to perform the task, including quantitative and qualitative requirements, warnings and limits.
 3. Evaluate the natural cues available.
 - b. Evaluate the lighting subsystems, quantitatively and qualitatively, as an individual subsystem against the defined requirements and operational environment.
 - c. Integrate the lighting components together and evaluate them collectively as a system.
 1. Evaluate and match luminance levels of each component.
 2. Evaluate total system workload and adjust components as necessary. (Use modified AD-33D maneuvers to measure workload in degraded visual conditions.)
 - d. Evaluate the system for component failures and determine the minimum acceptable configuration for each of the different types of heliports (see 9.1).
- 9.10 It is in the best interest of the industry to expand the FAA list of approved lighting in order to remove any barriers, however artificial and unintentional, to the introduction of new lighting technologies that may improve VFR and IFR heliport operations.
- 9.11 As the FAA develops and refines the requirements for heliport instrument lighting, care must be taken to develop all resulting specifications as functional performance specifications that detail the required characteristics of the light output and not merely the characteristics of a light source. As lighting technology has advanced, there are often several ways to produce a light output.
- 9.12 The most promising candidate lighting components and lighting systems should be tested in a variety of operational environments and under a variety of different weather conditions at different times of the year. If possible, test locations should be chosen that allow a wide variety of industry helicopter pilots to participate in this flight testing.
- 9.13 Most lighting systems used to date have employed incandescent lights in one form or another. Two exceptions that come to mind are Xenon flash tubes and EL lighting, although there may be others. The lighting at aviation landing sites has been primarily incandescent. Recent research efforts have attempted to review alternative lighting technologies. Some have been around for years and have not previously been used in the aviation field, and some are relatively new technologies that have only recently become cost effective. A number of these alternative technologies show promise as potential components of heliport and vertiport lighting systems.

- 9.14 Army tactical lighting systems have four portable lights arranged in an inverted "Y" to provide line-up and touchdown cues with an absolute minimum number of lights. This indicates that a simple line of lights will not provide an adequate cue. The pilot requires additional lights arranged at right angles to properly orient the line-up line and resolve the visual picture with the actual attitude of the helicopter.

REFERENCES

1. Gilstrap, J.B. and Richards, R.B.; NAVTOLAND Program Report, Development of Visual Landing Aid Requirements, Task 2 - Initial Analysis of Display Requirements, prepared for the United States Navy, Naval Air Engineering Center, Lakehurst, NJ; prepared by Pacer Systems, Inc., Billerica, MA; May, 1976.
2. Anonymous; FAA Memorandum; NAS Change Proposal (NCP) 12485; Federal Aviation Administration, Washington, DC, February 2, 1990.
3. Anonymous; Heliport Design, Advisory Circular 150/5390-2A; Federal Aviation Administration, Washington, DC, January 20, 1994.
4. Anonymous; FAA Order 8260.37, Heliport Civil Utilization of Collocated Microwave Landing Systems (MLS), Federal Aviation Administration, Washington, DC; September 27, 1991.
5. Anonymous; FAA Order 8260.42, Heliport Non precision Approach Criteria Utilizing the Global Positioning System (GPS), Federal Aviation Administration, Washington, DC; February 15, 1996.
6. Ernst, C. A.; Effects of Color to the Eye and its Importance for Heliport Lighting, University of Tennessee, Knoxville, August 1996, NTIS #AD-A311260
7. Kimberlin, R.D., Sims, J. P., and Bailey, T.E.; Heliport Lighting – Technology Research; FAA Report No. FAA/ND-98/1; Washington, DC; November 1998.
8. Hretsina, G. B.; Out of the Darkness, prepared by Reginald Bennett Inc. for presentation at the Approach Lighting Systems Symposium, Arizona State University East, Mesa, AZ April 15-18, 1998.
9. Mandler, M. B.; Conspicuity of Aids to Navigation: Extended Light Sources, U.S. Coast Guard Research and Development Center, Avery Point, Groton, CT; presented at the XIIth Conference of the International Association of Lighthouse Authorities; Holland; 1990.
10. Billman, B.R. and Schollenberger, S.; Helicopter Visual Approach Segment Approach Lighting System (HALS) Test Report ; FAA; Atlantic City, NJ; Report No. DOT/FAA/CT-TN89/21; June 1989.
11. Sulzer, R. L. and Poprocki, T. H.; Flight Test and Evaluation of Heliport Lighting for VFR, Federal Aviation Administration, National Aviation Facilities Experimental Center, Atlantic City, NJ, Project No. 430-206-01X, Report No. NA-69-2 (RD-68-61), March 1969.

12. Baillie, S. W., Kereliuk, S., Srinivassan, R., and Hoh, R.; Tracking Performance Requirements for Rotorcraft Instrument Approaches to Reduced Minima, Phase I – Preliminary Study; National Research Council Canada, Institute for Aerospace Research, Aeronautical Note IAR-AN-70 NRC NO. 32137, Feb 1991.
13. Whittenburg, J. A., Vaughan, W. S., Havron, M. D., and Cavanaugh, C. R.; Airport/Heliport Marking and Lighting Systems: A Summary Report on Human Factors Research, (FAA-RD-64-94), McLean, VA: Human Sciences Research, Inc. (DTIC No. AD 608049); June 1964.
14. Wick, R. L. Jr., MD, Tischer, J. L., Jr., MD; One Eye or Two? How Many Are Needed to Fly?; FAA Aviation News, May-June 1995, p. 23-24.
15. Lescher, W. K. LCDR, Smith, P. D. LT, Long, K. R.; SH-60B Degraded Visual Landing Aids Evaluation Aboard USS Cushing (DD985); Naval Air Test Center, Patuxent River, MD, Report NO: RW-14R-90, April 1990.
16. Brown, G. S.; State-of-the-Art Survey of Low Cost Visual Glideslope Guidance Aids; FAA Report No. NA-77-9-LR; National Aviation Facilities Experimental Center, Atlantic City, NJ, March 1977.
17. Johnson, W. W., Andre, A. D.; Visual Cueing Aids for Rotorcraft Approaches; NASA Ames Research Center, Moffett Field, CA, Presented at Piloting Vertical Flight Aircraft: A Conference on Flying Qualities and Human Factors, San Francisco, CA, 1993.
18. Owen, D. H., Freeman, S. J., Zaff, B. F., Wolpert, L.; Perception of Self Motion; Operations Training Division, Williams Air Force Base, AZ, November 1987.
19. Hoh, Roger, H.; The Effects of Degraded Visual Cuing and Divided Attention on Obstruction Avoidance in Rotorcraft; prepared for the Starmark Corp., Arlington, VA and Systems Control Technology Inc., Arlington, VA 22202, under contract to the Federal Aviation Administration December, 1990.
20. Anonymous; Louisiana Hospital Heliport Study Vol. I, Development Guide; Louisiana Department of Transportation and Development, Office of Aviation and Public Transportation; April 1982.
21. Fontaine, S. A., Evaluation of a Heliport Lighting Design During Operation Heli-STAR; FAA Report No. DOT/FAA/ND-97/20; Washington, DC; July 1998.
22. Hart, D. C., ADS-33C Flight Test Maneuvers Validation in a Degraded Visual Environment; Presented at the American Helicopter Society 50th Annual Forum, Washington, DC, May 11-13, 1994.

23. Anonymous, Aeronautical Design Standard (ADS)-33D, Handling Qualities Requirements for Military Rotorcraft, AVSCOM, U.S. Army Aviation and Troop Command, Directorate for Engineering; St. Louis MO; July 1994.
24. Fontaine, S. A and McConkey, E. D.; Heliport Lighting – U.S. Park Police Demonstration; FAA Report No. DOT/FAA/ND-98/4; Washington DC; November 1998.

APPENDIX A

ACRONYMS

AC	Advisory Circular
AIP	Airport Improvement Program
AVASI	Abbreviated Visual Approach Slope Indicator
BA-VASI	Bar Alignment Visual Approach Slope Indicator
DLGI	Diode Laser Glideslope Indicator
DWP	Decision Waypoint
EL	Electroluminescent
FAA	Federal Aviation Administration
FARA	Final Approach Reference Area
FATO	Final Approach and Takeoff Area
FLOLS	Fresnel Lens Optical Landing System
GE Bi-Color	General Electric Bi-Color
GPS	Global Positioning System
GSI	Glide Slope Indicator
HALS	Helicopter Approach Lighting System
HAPI	Helicopter Approach Path Indicator
HAPI-PLASI	Helicopter Approach Path Indicator-Pulse Light Approach Slope Indicator
HELI-PLASI	Helicopter Pulse Light Approach Slope Indicator
HELI-STAR	Helicopter Short-Haul Transportation System and Aviation Research
HILS	Helicopter Instrument Lighting System
Hz	Hertz
ICOLS	Improved Carrier Optical Landing System
IFR	Instrument Flight Rules
LED	Light Emitting Diode
MAWP	Missed Approach Waypoint
mi	Statute Mile
MINI-PLASI	Miniature Pulse Light Approach Slope Indicator
MLS	Microwave Landing System
MOLS	Mirror Optical Landing System
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NAVTO LAND	Navy Vertical Takeoff And Landing Capability Development
nm	Nautical Mile
PASI	Passive Approach Slope Indicator
PCOLA	Pulse Coded Optical Landing Aid
PLASI	Pulse Light Approach Slope Indicator
POLS	Portable Optical Landing Aid
POMOLA	Poor Man's Optical Landing Aid

PVG	Precision Visual Glideslope
SAIC	Science Applications International Corporation
SAVASI	Simplified Abbreviated Visual Approach Slope Indicator
SGSI	Stabilized Glide Slope Indicator
TLOF	Touchdown and Liftoff Area
"T"-VASI	T-Bar Visual Approach Slope Indicator
"T"-VASI (Abbreviated)	Abbreviated T-Bar Visual Approach Slope Indicator
U.S.	United States
USCG	United States Coast Guard
UTSI	University of Tennessee Space Institute
VAC	Volts Alternating Current
VAPI	Visual Approach Path Indicator
VASI	Visual Approach Slope Indicator
VFR	Visual Flight Rules